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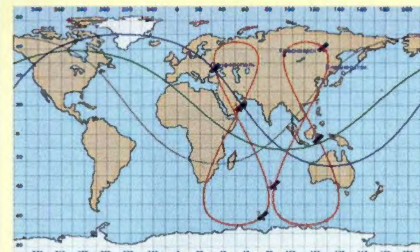

Satellite Navigation Systems – of which GPS is just one – simply work! But it's not all that simple, as Dr David Maddison's feature will tell you. In fact, it's rather complicated! – Page 14

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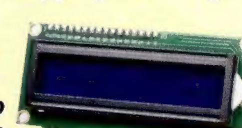

This Digital Panel Meter was made to suit our new 45V/8A Power Supply. But it could be used with a range of projects – Page 90

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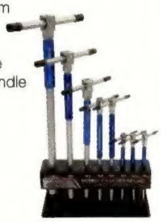

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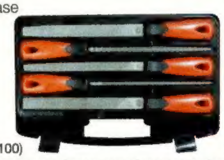

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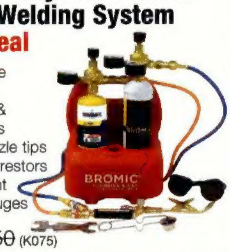

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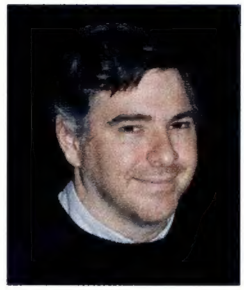
Editorial Viewpoint



Hand-held devices discourage creativity

There's no denying that smartphones and tablets are very handy devices. They give you the ability to look up information just about any time and anywhere. For example, there are times when I need to know the pinout of a device in front of me. The easiest and quickest way is often to do a web search on its part code and then read the data sheet on my phone's screen.

But I don't understand people who think that they can 'get rid of' their computers because they have a smartphone and/or a tablet. Sure, these devices are computers, and they can do many things that a desktop computer can. But they can't do it all, nor can they do many of those things particularly well.

To a large extent, replacing your proper computer with a mobile device relegates you to a being a 'consumer' of information, rather than a creator or producer of it.

Even something as simple as writing a moderately-sized e-mail becomes a difficult task on a smartphone or tablet. Typing hundreds of words becomes a chore, and the risk of mistakes becomes much higher (auto-correct doesn't allways get it write!). An external keyboard makes this easier, but the small portable ones are not very nice to use, and it's hard to type quickly on them.

And while there are millions of "Apps" available for Android and iOS, surprisingly few have the features you need to be creative (besides drawing and painting, which tablets have always been good for). You can pretty much forget about drawing up circuits or PCBs in a CAD program. All the ECAD software I've tried on Android devices has been a joke.

Even if a proper ECAD program was ported to a mobile platform, and the device's hardware could handle it, using it with a small(ish) touchscreen would be a nightmare. It would take hours to do something that would take minutes on a desktop or notebook computer. Without a proper mouse and keyboard, your productivity would be virtually nil.

Another vital aspect that a lot of people forget about is ergonomics. You can't really hold a mobile device in front of your face for very long, so you end up having to lay it down on a desk (or prop it up on a stand). But then you're looking down for hours at a small screen, causing neck and eye strain, and you'll get sore arms from prodding the screen.

A properly set-up PC does not have this problem. With a good keyboard, mouse, screen and chair you can be productive all day without straining anything. (It's arguably healthier to avoid sitting down all day, but unfortunatey, this is the reality of modern office work.)

So I'm concerned for the younger generations who are growing up surrounded by mobile devices. They may have limited exposure to 'proper' computers. I suppose school will expose them to computers and productivity software, hopefully giving them opportunities to learn how to code, write prose, draw diagrams and so on. That should spur their creativity.

I think it's essential to be creative and 'make' stuff, whether that is art, science or engineering-based, or something else. Of course, you don't need a computer to do that, but more and more these days, computers are involved in creative activities. I can even imagine sculptors taking advantage of 3D printers to create tricky shapes.

So, keep your computer. Be productive. I don't know about you, but I get bored with passive entertainment after a while, and I have to go off and do something productive. It's just so much more engaging, and you get a much better sense of satisfaction from having done something useful.

Nicholas Vinen

Reading vintage core memories

In the Mailbag section of the September 2019 issue (page 4), Professor James Goding wrote in saying that he had a core memory module, possibly still containing data. There is now only one team of which I am aware that can read and dump these memory modules. Look up the YouTube channel "CuriousMarc": siliconchip.com.au/link/aavt

He and his team of (amateur) steely-eyed missile-men have successfully designed and manufactured new equipment that can read these core and rope memories. Professor Goding may wish to contact Marc, or at least watch their captivating series on the journey to restore a real Apollo Guidance Computer to working condition.

Michael Kingsford Gray,
Adelaide, SA.

How a vibrator works

Readers of the Vintage Radio article "Kriesler Farm Radio model 31-2" (September 2019; siliconchip.com.au/Article/11930) should be made aware that the circuit diagram in Fig.2 "Operation of a Synchronous Vibrator" is incorrect.

As drawn, the vibrator would not work. The energizing winding is shown continuously powered from the battery; with this connection, the reed would simply 'pole' to one side and never release. The correct circuit diagram is to be found as Fig.32.2 in the Radiotron Designers Handbook (Fourth Edition) on page 1203.

A further error is in the caption to Fig.2, in which the capacitor shown is referred to as a "filter capacitor". This is actually known as a "timing capacitor"; its value is chosen to resonate with the inductance of the transformer.

For more information on vibrators refer to my article "Refurbishing a Vibrator" in the HRSA journal Radio Waves Number 149, July 2019 (page 28).

Ross Stell,
Kogarah, NSW.

Response: you are right that there is

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an error in Fig.2, but it is more subtle than you suggest. The vibrator reed should have been shown in a central position, not making contact on either side. This is how the reed actually rests when power is not applied, and a vibrator with this configuration will (and does) work.

This mistake was unfortunately introduced when it was re-drawn for publication; the original diagram supplied by Graham Parslow was correct.

Regarding the so-called "timing capacitor", Ian Batty comments: the vibrator's operating frequency is determined by the stiffness of the reed, the mass of the electromagnetic tip that responds to the coil's magnetic field and the magnetic flux created by the current through the coil. External components have no important effect on the frequency.

The buffer capacitor (erroneously called the "timing" capacitor in some incorrect descriptions) is a critical protective component. It is ***not*** *there to resonate with the transformer. Resonance would cause the system to act like the tank circuit in a Class-C power amplifier, converting current pulses into sinewaves.*

Any check of the supply to a vibrator-supply rectifier will show it to be substantially square. In fact, for highest efficiency, we want a square wave at the rectifier.

At some point in each half-cycle, the reed makes no electrical contact; there is a brief 'dead-band' between the time the contacts on the reed break connection with one fixed contact and re-make connection with the opposite fixed contact. For this brief period, the transformer primary current falls to zero. This collapses the transformer's magnetic field near-instantaneously.

This, according to Lenz's Law, creates a very large voltage surge. This is how Kettering ignition systems work in petrol engines, to generate the high voltages needed for a spark plug from a low-voltage supply.

If allowed to occur, these voltage spikes would drastically shorten the vibrator contact's lives and create massive interference, if not causing insulation breakdowns on the secondary side. The buffer capacitor damps these voltage spikes. It's commonly a 1.6kV-rated type for this reason.

You may see sets with buffer caps on the primary and secondary, but it's more common for them to be on the secondary where a lower (more practical) capacitor value can be used.

One of my mates who works on vintage car radios has seen buffer capacitors fail, leading to vibrator destruction. He advises routine replacement if a set is in for service, as an insurance policy against future failures. Some of these capacitors are 50~60 years old now.

Ground symbol does not necessarily indicate Earth

I have noticed that you have used the standard Earth symbol (⏚) incorrectly in some cases. It is normally used to denote an 'Earth' connection, ie, connected to an Earth stake in the ground for a protective function. In our power systems (TN-C-S), the Earth connection is bonded to the Neutral side of a transformer. As such, it is safe to touch. In fact, we may do so many times a day, for instance, when opening the refrigerator, dishwasher etc.

In the Universal Dimmer project (February 2019; siliconchip.com.au/Series/332), it is used to show a common connection on the schematic. If you consider this is nearly at Active potential with respect to Earth, it is not at a safe potential to touch. If this were a battery piece of equipment, one could argue that it does not matter. But in this case, it could be misleading and dangerous.

This is akin to using a green/yellow wire for an Active conductor, strictly forbidden by AS/NZS 3000! I suggest that a different method be used to show the 0V rail, for example, an inverted "T" with a 0V designator.

Thanks to you and your staff on the excellent magazine, it is always interesting to read.

Lindsay Freund,
Para Vista, SA.

John Clarke responds: it is true that the ground symbol that we use to indicate the 'common' connection in our circuits started as indicating an Earth connection.

But that is not how it has been used for many decades now. Since the days of valve radios, it has generally been recognised as being a way of simplifying a circuit drawing, so that common connections do not have to be drawn as lines.

This is the first complaint that we have received about using the ground symbol for non-Earthed points since I started working at Electronics Australia in 1979. We have done many mains projects since then, some of which had grounds tied to (or near) Active.

I can see how it may be possible to get the impression that these points in the circuit are connected to Earth. But we make a clear distinction in our diagrams by using the chassis Earth symbol to indicate Earth, and reserving the ground symbol as a wiring common symbol.

The inverted "T" that you have suggested could be misconstrued as safe for similar reasons. It is just an abbreviated form of the ground symbol.

I do not consider the ground symbol that we use as synonymous with using the green/yellow Earth wire for a live connection. The green/yellow Earth wire is legislated as only being used for Earth connections, and we fully agree with that. But the legislation does not extend to the use of symbols in circuit diagrams. It leaves symbol conventions up to the people drawing the diagrams.

We could draw common circuit connections differently when they are floating, but any new common symbol (such as inverted T) would need to have a warning if the voltage on that connection is liable to be unsafe.

One option would be to continue using the ground symbol for low-voltage circuits and the inverted T for high-voltage common, with the voltage warning next to it. We will consider whether that is necessary the next time we design a project with a high-voltage common rail.

Colour video from the moon landings

The letter from Alan Hughes in your September issue on colour video of the US moon landings (Mailbag, page 8) reminded me of my experiences at the time, working for ABC Sydney. It was a long time ago, so some of the details may be a little off, but this is how I recall it happening.

For the second US moon landing (Apollo 12, November 1969), they took with them an unusually small colour TV camera. The modern method for making single-tube colour cameras (the dual-colour fine line optical filter) hadn't been thought of then.

It takes about 1000 litres of rocket fuel to get one kilo into orbit, and more still to the moon. So the propulsion team said there was no way the astronauts were taking a heavy three-tube colour camera along.


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So instead, they fitted a rotating wheel containing three coloured plastic filters (red, green & blue) in front of a monochrome camera tube. It was synchronised so that each TV field was shot through a different coloured filter. Each set of three fields could then combine upon reception to produce colour video.

When the time came, the camera fired up and produced slightly flickery but quite watchable colour pictures. Of course, in Australia, most of the public (including me) only saw them in monochrome as we didn't have colour TV until 1975.

After showing us breathtaking pictures of the Moon's surface for just a short while, unfortunately, the camera was accidentally aimed at the sun. The coloured filters immediately bubbled and buckled the filter wheel. It ground to a halt.

Unfortunately for all the world watching, the wheel stopped with its spoke in front of the camera tube. No amount of hitting the side of the camera would free it up, and so that was the end of video for Apollo 12.

The camera designers, determined that this wouldn't happen again, modified the design. I assume they did this by adding an infrared filter to protect the colour wheel. This improved camera made it to the moon on the Apollo 15 flight (July 1971).

By this time, our TV station had taken delivery of a colour Telecine chain for training purposes; it came with a large colour monitor with red, green and blue baseband video inputs. By a stroke of good fortune, I was on duty in Telecine maintenance over the few days of the Moon landing.

Fortunately for us, the Moon was in the Southern sky for some of this most critical time, and so Australian dishes received the Moon pictures and sent them on to America. In those days, all TV signals were carried around the country by Postmaster-General's Department (PMG), the predecessor of Telstra.

At that time, any self-respecting TV station had cables feeding signals to and from the PMG. It didn't take us long to get a clean feed of the signal straight from the Moon.

Looking at the flickering pictures, I thought it shouldn't be too hard to decode the colour. I grabbed a couple of RTL JK flipflops and wired up a divide-by-3. I then used a couple of TTL NAND gates to decode the three states and used them to drive three metal-can NPN transistors.

I tried using these to switch some small cradle relays, which were quite abundant around the station. Not being designed for video, they leaked at high frequencies, switched too slowly and bounced all over the place.

Someone asked me why I didn't try reed relays. I said: where am I going to get some at short notice? This person pulled out a small cardboard box which had half a dozen 12V reed relays, complete with coils. I slapped them in-circuit, and lo and behold, we had colour pictures from the Moon on the monitor.

Unfortunately, they were the wrong colours, but we soon got the cables into the right colour sockets. Fast movements looked a bit weird, with the edges having flickering colours like a barber's pole running up and down them. But as most movements on the Moon were done slowly, it looked terrific.

By the end of the third day, the reed relays were starting to muck up. You could see black lines at the top of the picture, and they repeated several times down the picture with a few good lines in between. As the black lines got worse, the sync signals got chewed up, and the top of the picture started to tear. The reeds were starting to bounce.

A quick calculation (3 days × 12 hours × 3600 seconds × 60 fields per second ÷ 3 relays) showed that they had each opened and closed more than 2,500,000 times since we first started watching the Moon pictures. No wonder they were wearing out!

Gary Yates,
Frenchs Forest, NSW.

Advantages of motor current limiting

I want to comment on Gianni Pallotti's 4DoF Gamer's Seat project in your September issue (siliconchip.com.au/Article/11912). What an impressive project! It is pure mechatronics, and Gianni deserves applause for tackling such a project successfully.

I bet that at some point during the development of this project, he wished he had not started it. Projects that require electronic and mechanical knowledge and skill, plus programming, can develop into monsters. Although this project is not at the high end of complexity, it would still have been a serious challenge.

However, I noticed that the motor drivers are not current-limited. Permanent magnet motors draw heavy currents at startup and with a Bosch industrial version, the stall current was stated at 28A. I have used windscreen motors several times, and I vaguely remember early Holden motors peaking at something like 11-14A.

The problem is that the power supply must be big enough to supply this large current. If it does not have the current rating or considerable surge capability, it may fail or at least 'drop its bundle'.

I measured Bosch and Holden motors as drawing approximately 2A at no load and approximately 4A under normal load. If a current limiter (constant current circuit) set at 6A is used to supply Q2 and Q4 in each H-Bridge module, a much smaller and cheaper power supply can be used.

Permanent magnet motors do not deliver substantially more torque with a high stall current. The maximum current can be limited to a much lower value with little reduction in peak torque.

The most efficient motors will have low armature and brush resistances and therefore will have high stall currents, regardless of their power rating. The proper solution is to fit current limiting.

George Ramsay,
Holland Park. Qld.

Response: we believe that Gianni's specified power supply is more than capable of dealing with the peak power requirements of his design. Regardless, your comments are interesting and may be useful to constructors or those driving motors for other purposes.

Impressed with the Micromite series of modules

I am impressed by the performance and versatility of the Micromite series of devices. The new Explore-28 will no doubt fast track many personal projects.

Having built projects using mostly PIC microcontrollers programmed in C, the challenge was always the choice of display.

For the sake of avoiding the more complex interfacing and programming requirements of a graphics display, I would often settle for a two- or four-line alphanumeric LCD. But the Micromite BackPack and the Explore 100 changed all that.


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Initially, I thought the BASIC code would be noticeably slower and consume more memory, but I was pleasantly surprised by both the performance and the amount of code that one can load into the device.

I am sure the versatility, ease of use and low cost will also attract more school and college students venturing out into the world of electronics – well done in promoting these devices and delivering several great projects based on the Micromite! I think it is a game-changer for future projects, as it allows one to focus on the design and delivery of the device being controlled.

As an example, I modified Jim Rowe's ADF4351 sample program for the Micromite BackPack (May 2018; siliconchip.com.au/Article/11073) to provide more control of the frequency generator module. I added a sweep feature with dwell, space, swing and power level controls. (The code is available for free from siliconchip.com.au/Shop/6, associated with this month's issue.)

The Micromite easily handles the additional code, and there is still plenty of room left for more features, such as saving user-defined settings, which made me wonder whether the Micromite should perhaps include an onboard EEPROM.

For saving user settings, the flash memory in the Micromite will suffice for up to 20,000 write/erase cycles, but one does need to be careful if using it for more frequent writes.

As the manual states, if writing to the flash every second, the 20,000 writes would be used up in six hours, compared to 50 years if only doing one write per day.

Steve Matthysen,
Valdora, Qld.

Response: most of the credit for the Micromite series should of course go to Geoff Graham, Graeme Rixon, Peter Mather, Robert Rozee, Serge Vakulenko and the others who helped develop the modules and software.

The low-cost DS3231 real-time clock module which we have used in many of our Micromite-based projects has an onboard I^2C EEPROM, which is quite easy to use.

You can probably get an EEPROM that can be soldered to the flash/RAM IC pads provided on the V3 BackPack PCB (August 2019; siliconchip.com.au/Article/11764).

Note that there are also flash writing strategies for saving settings which can dramatically extend the life of the flash, making it practical to use for relatively frequent updates.

Microchip's "Data EEPROM Emulation" code (siliconchip.com.au/link/aavu) is a good place to start if you want to implement a similar scheme in MMBasic.

DAB+/FM/AM Radio noise

Further to my e-mail on the DAB+FM/AM Radio (siliconchip.com.au/Series/330) that you published in the Ask SILICON CHIP column (October 2019, page 110), I re-soldered all of the components around IC5, but there was no improvement in the background noise situation.

While prodding around my radio board with my newly acquired/constructed DSO138 oscilloscope (as reviewed in your April 2017 issue – siliconchip.com.au/Article/10613), I found spikes at about 120Hz in lots of places, including the 5V rail. Given that the 5V supply to the radio board comes from the Explore 100, I checked on my other Explore 100 module and was surprised to find the same spikes there.

I experimented by removing the touchscreen from the Explore 100 entirely. When I powered up the radio in this state, the sound in my headphones was perfect. The set happened to be tuned to an FM station (I don't know which one; I didn't have a screen) that was playing some classical guitar music. It was beautiful.

Also, the background noise at start-up, that isn't restricted to the headphones, was absent. When I plugged the set in, the silence in my headphone was such that I wondered if the set was actually working!

In anticipation of the possibility that the female header (CON9 on the Explore 100) is causing the background noise, I went over all the 40 pins on the Explore 100 board and re-soldered them. But when I re-assembled the radio with the screen and plugged it in, both background noises had come back with a vengeance...

I then tried adjusting the touchscreen backlight brightness and found that setting it to 100% (maximum brightness) caused the noise to disappear. So it seems likely that it is related to the PWM backlight control.

So it seems that the screens are my problem. I would appreciate any

comments you have on that, please. If I understand correctly, noise can be smoothed out with strategically placed filters of one sort or another. But where on these circuit boards could they be installed? And do you have any idea why the background noise is only heard out of the headphone socket, and not the loudspeakers?

I bought my 5-inch touchscreens from Amazon. Perhaps they are different from the ones you used in your prototypes. I would quite happily buy another screen. But how can I be certain that a new screen would be OK?

David Plumley,
Noumea, New Caledonia.

Response: we tested adjusting the PWM backlight brightness on our prototypes to ensure that this was not a source of interference, and didn't hear the noise you are describing, so it is quite baffling. It could be due to differences in the display, but it seems more likely that it's a soldering or component problem somewhere on the radio board, which is increasing the interference pick-up.

The audio output stage runs directly off the 5V rail from the Explore 100 via pin 3 of CON3. We suggest that you disconnect this pin and try connecting 5V from the Explore 100 to CON9 via a resistor (say 10-47Ω), with a high-value electrolytic capacitor connected across CON9.

If that kills the noise, then it's definitely getting in through the 5V rail, and you can try other approaches to remove it (or just find a convenient place to hide those added components).

We bought our screens from: www.aliexpress.com/item/32665326615.html

RF Signal Generator needs a load to test power switch

I am partway through building the AM/FM/CW Scanning Signal Generator project (June & July 2019; siliconchip.com.au/Series/336). I have reached the point in construction where the article suggests "Early Testing".

Following the instructions, I took the opportunity to test the power switching and connected a 12V DC supply. When I pushed S3, 4.9V DC appeared at JP1 as outlined in the text. But when I pushed S3 again, the unit did not switch off.

I tried changing various components within the switching circuitry, including the 10kΩ resistor, as mentioned in Notes & Errata (September 2019), all to no avail.

After a bit of thought, I realised that there is no load within the circuit as IC1, the AD9850 and other RF section components had yet to be fitted. I clipped a 10Ω resistor across the supply (from JP1 and GND) to give a 500mA load, and the unit switched on and off as expected.

I hope this may save some readers some head-scratching in the future.

Warwick Guild,
Dunedin, New Zealand.

Less accurate voltage reference probably counterfeit

I read your article on AD584 Precision Voltage References (July 2019; siliconchip.com.au/Article/11706). In it, Jim Rowe writes that the supposedly highly-precise AD584LH was actually further from its nominal voltage than the lower-grade JH/KH ICs that he tested.

The explanation is hinted at in the article, "assuming they are genuine". There are many likely-fake LH modules being sold, with the price of the complete module being less than what the LH IC alone should cost.

Given that the alleged LH performed worse than the other two, you may have a reject part that some enterprising vendor has re-badged as a high-priced LH. Do a Google search for "AD584LH fake" for more discussion on the dodginess of some of the stuff out there, eg: http://siliconchip.com.au/link/aauw

Peter Gutmann
Auckland, New Zealand.

Response: we had a feeling, based on the results, that the part was not a genuine AD584LH but we had no proof, as it was within specifications. As the part is no longer being manufactured, it's hard to say where you can reliably get the genuine article.

Mains hazard warning alarm

In the April 2019 issue, Paul Smith of King Creek wrote in, wondering about a neutral fault hazard detector. SILICON CHIP published my design for a MEN System Hazard Detector in the Circuit Notebook section of the December 2014 issue (siliconchip.com.au/Article/8124). It is safe and has an audible, strobe light alarm.

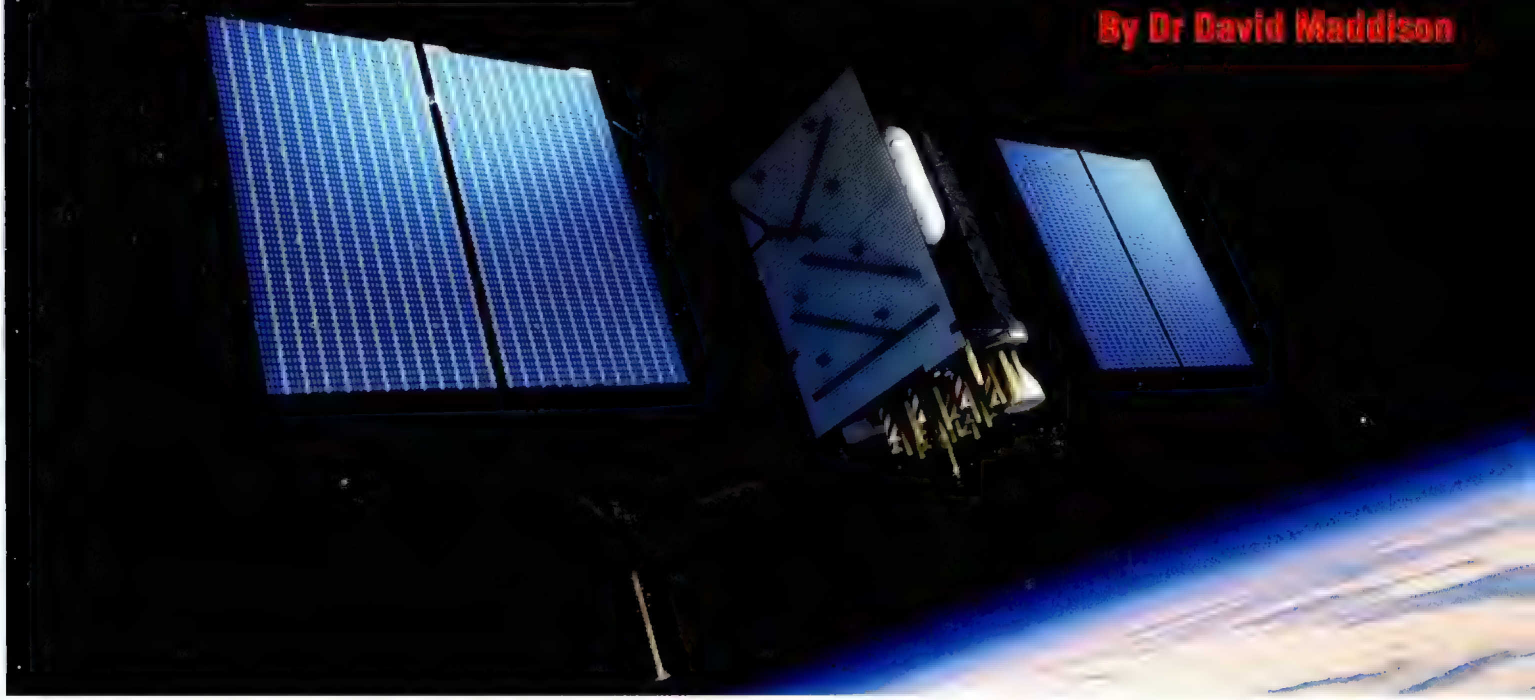
Dr Hugo Holden,
Maroochydore, Qld. SC

How does satellite navigation work?

A look at GNSS systems

Global Navigation Satellite Systems (GNSS), of which the familiar GPS (Global Positioning System) is but one example, are now ubiquitous and used in everyone's daily lives. Most people do not even know the origin or workings of the location and mapping functions built into the smartphones that they carry. To them, it's just 'there', and it works. But there is a lot going on behind the scenes!

By Dr David Maddison



In the September 2018 issue of SILICON CHIP, we published an article on Augmented GNSS (siliconchip.com.au/Article/11222), describing how the accuracy of satellite navigation systems can be enhanced beyond what is ordinarily available, through various augmentation systems (eg, SBAS – Satellite-Based Augmentation System).

This augmentation is not needed for ordinary users but is for applications such as aircraft landing, precision agriculture and self-driving cars etc.

We also looked at a predecessor system to GPS, the terrestrial based Omega Navigation System in the September 2014 issue (siliconchip.com.au/Article/8002).

But so far, we have not actually described in detail how satellite navigation systems work. This article corrects that omission. We will go back to basics, to describe how the regular (non-augmented) GNSS systems operate.

In the beginning . . . the word was the US GPS

The first GNSS system put in place, and the one most people are familiar with, is the US Global Positioning System (GPS). This was developed for the US military, both for navigation and to ensure better accuracy with their weapons systems (with the benefit of limiting unintended civilian casualties).

This system was also made available free of charge worldwide, with reduced accuracy at first ("selective availability"), then later with the full available accuracy. The USA turned off selective availability on 1st May 2000 and undertook never to use it in the future.

Part of the motivation for this was to prevent future tragedies such as Korean Air Lines Flight 007, which was shot down by the Soviet Union in 1983 after inadvertently flying into Soviet air space, due to a navigational error.

Newer GPS satellites, or Space Vehicles (SVs) as they are called, don't even support selective availability.

While the US Global Positioning System was the first, the following systems have since come into service, or soon will be: GLONASS (Russian; fully operational), Galileo (EU, to be fully operational by 2020) and BeiDou (China, also to be fully operational by 2020). There are also two regional

systems: NavIC (India) and QZSS (Japan).

Then there are the following augmentation systems which provide greater positional accuracy (down to cm or even mm) and which were described in the September 2018 article: WAAS (USA), EGNOS (EU), MSAS (Japan), GAGAN (India), SDCM (Russia), WAGE (US Military), SBAS (Australia, test-bed) and the commercial systems StarFire, C-Nav, Startfix, and OmniSTAR.

Newer satellite navigation receivers are 'multi-constellation' types which support more than one of the above GNSS systems and can have access to over 100 satellites.

This makes position fixes in "urban canyons" and challenging terrain easier, as there is a higher likelihood of having more satellites visible directly overhead, also avoiding multi-path reflections from satellites that are not directly in the line of sight.

(Above and opposite): an artist's impression of the latest generation GPS Block IIIA satellite by Lockheed Martin, first launched December 23, 2018. These offer three times greater positioning accuracy than their predecessors, increased signal power and much-improved resistance against jamming. The satellites of the GPS constellation are named NAVSTAR (Navigation Satellite Time and Ranging) with various numbers to identify them. See the video titled *"Building the Most Powerful GPS Satellite Ever - GPS III"* at: siliconchip.com.au/link/aavj

Basic operating principles

The same basic operational principles apply to all GNSS systems. Each system has a group of satellites in orbit, known as a constellation. Each satellite sends a continuous signal to Earth which contains data such as the satellite ID, the current time onboard the satellite, the position of the satellite and other data. For GPS, this encoded information is called the Navigation Message.

All of the satellites in a constellation are synchronised with the same time reference, which is achieved using extremely accurate atomic clocks onboard each satellite and on the ground.

To achieve a full position fix, in theory three satellite signals at sea level are sufficient (where sea level represents the roughly spherical shape of the Earth, the so-called reference ellipsoid or 'geoid' which are accurate models of the exact shape). Four satellites are required to also compute altitude above sea level.

To get a position fix, two fundamental things need to be established. The first is the distance from the user's receiver to three, four or preferably more satellites.

This is called "trilateration" in the specific case of three satellites, or "multilateration" for three or more.

This gives a relative position of the receiver with respect to those satellites at the time of their transmission. To calculate the user's location, it's therefore also necessary to establish the position of the satellites at the time they transmitted their signals, which is encoded in the data stream along with the time of transmission.

This then gives the approximate location of the receiver on the Earth's surface or above it. These measurements are then followed by many corrections and iterative adjustments to get a more exact positional fix.

Determining the distance to the satellites

Radio signals travel at the speed of light, ie, 299,792,458m/s

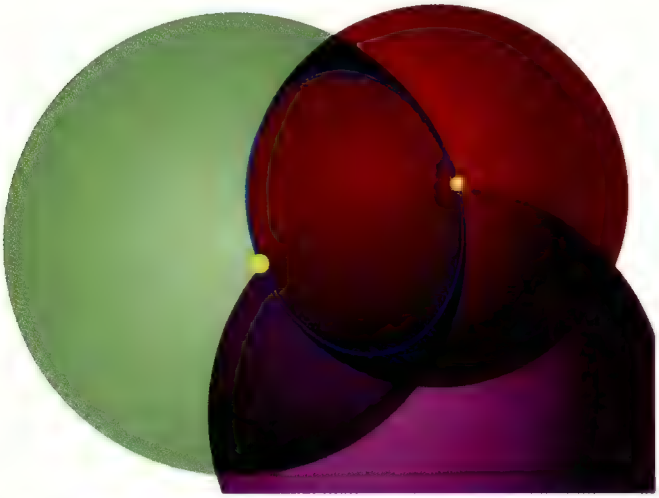


Fig.1: the intersection of three spheres, with radii defined by the distance between a group of satellites and a receiver. This shows how the intersection of two spheres produces a circle (blue), and the addition of a third sphere defines two points on that circle (yellow).

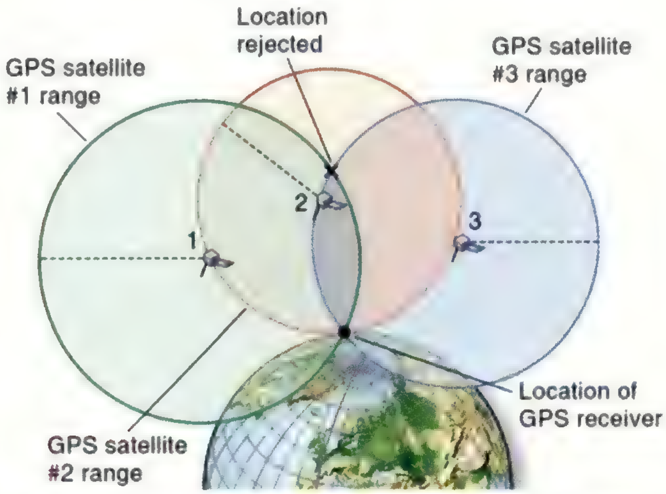


Fig.2: the intersection of spheres representing the distance from a receiver to three satellites, showing the two possible locations of the receiver with one point being obviously wrong and rejected. A fourth satellite will establish additional information such as altitude and help in calculations to correct the receiver time clock.

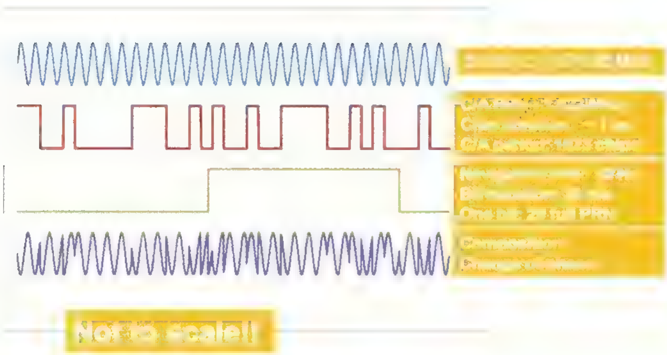


Fig.3: **the structure of GPS signals including a carrier, pseudo-random noise (PRN) code, navigation data (one bit for every 20 PRN cycles) and the resulting combined signal, that is transmitted by the satellite. C/A stands for coarse/acquisition code.** *Image source: José Caro Ramón, Head of GNSS Augmentation Systems and Services at GMV, PMP; Creative Commons Attribution-Share Alike 3.0 Unported license.*

in a vacuum. If we know the delay between the transmission of a signal from a satellite and it being received on Earth, we can determine the distance between the transmitter and the receiver.

This propagation delay calculation requires that the time the signal leaves the satellite and the receipt time at the receiver be known. The signals leaving the satellite have a time stamp of the departure time.

Ideally, the receiver would have an atomic clock synchronised to the same time as the satellite clock, but generally, this is not the case; not everybody has pockets large enough to carry around an atomic clock, or the batteries required to run it!

We will discuss how that problem is dealt with later.

Knowing the exact time is essential as even a 1ns (one-billionth of a second) clock error at the receiver compared to the satellite will result in a 30cm positional error; that is how far radio waves travel in 1ns.

Knowledge of the propagation time of a signal (ie, distance) from one satellite to a receiver locates the receiver on a sphere around the satellite, with its radius being the calculated distance (see Figs.1 & 2). Knowing you are somewhere on a sphere is not that useful, so more information is required.

If the distance to a second satellite is known, then the receiver can be determined to be somewhere in a sphere surrounding that satellite as well. The receiver location is on the intersection of two spheres, which describes a circle. So we know the receiver is somewhere on that circle. But that is still not enough information for a complete position fix.

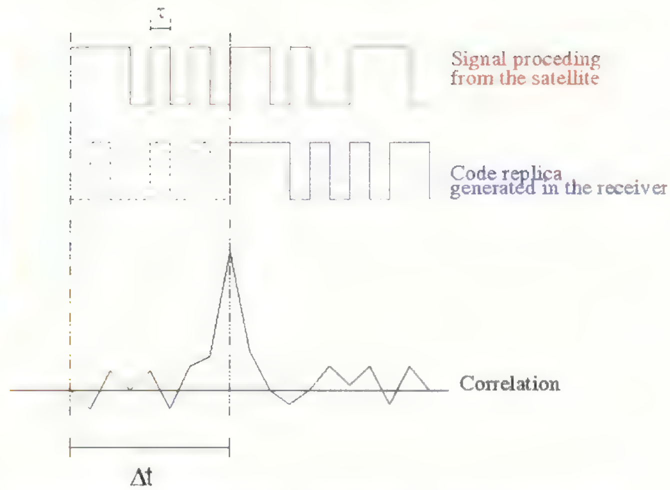


Fig.4: how the signal travel time from the satellite to the receiver is determined. The receiver knows the matching PRN code expected from each satellite. The PRN code within the receiver is shifted until the maximum correlation is found between the received and expected signals, and the offset required to do this establishes the travel time, Δt. In this case, if the receiver code was shifted all the way to the left, there would be an exact correlation. *Figure source: Carlos Lopez, https://gssc.esa.int/navipedia/index.php/GNSS_Basic_Observables*

With a third satellite, we calculate a third sphere, and this also has to intersect with the circle formed by the intersection of the first two spheres. When a sphere intersects with a circle, it does so at two points.

So with three satellites we then have two possible positions of the receiver. The question then is how to determine which of those positions is the actual location.

Usually, the position nearest Earth would be chosen as the obvious location, and the second position would be rejected.

If a fourth satellite is used, it can unambiguously establish which of the two possible positions is the correct one without having to guess. The fourth satellite is needed for another reason as well as will be discussed later.

Note that at this point, only the relative position of the receiver with respect to the satellites is known. So to determine the actual position of the receiver with respect to the Earth, knowledge of the satellites' position is required.

The full GPS interface specification

If you are interested in seeing the core technical document that defines everything you need to know about the "interface" between the "space segment" of the Global Positioning System and the "user segment", some of it is contained in the 224-page document named "Interface Specification IS-GPS-200J, May 22, 2018", available at: siliconchip.com.au/link/aavk

This describes the structure and content of data transmitted from GPS satellites on radio frequency links L1 and L2. Related technical documents can be found at: www.gps.gov/technical/

A useful book on GPS is P. Misra and P. Enge, Global Positioning System: Signals, Measurements and Performance, Ganga-Jamuna Press, 2011.

Relativity effects and corrections

Satellite navigation is an everyday situation where Einstein's theories of Special Relativity and General Relativity have to be taken into account.

Firstly, because the satellites are moving relative to the observer (about 14,000km/h for GPS), there is a time dilation effect. Special relativity says that the clock on board the satellite will fall behind ground-based clocks by about 7μs per day. Bearing in mind radio waves travel about 30cm per nanosecond, this would amount to an error of 2.1km per day.

Secondly, massive bodies such as the Earth distort space-time and the closer to such a body a clock is, the slower time seems to go relative to an outside observer.

Since the satellites are high above the Earth, an observer

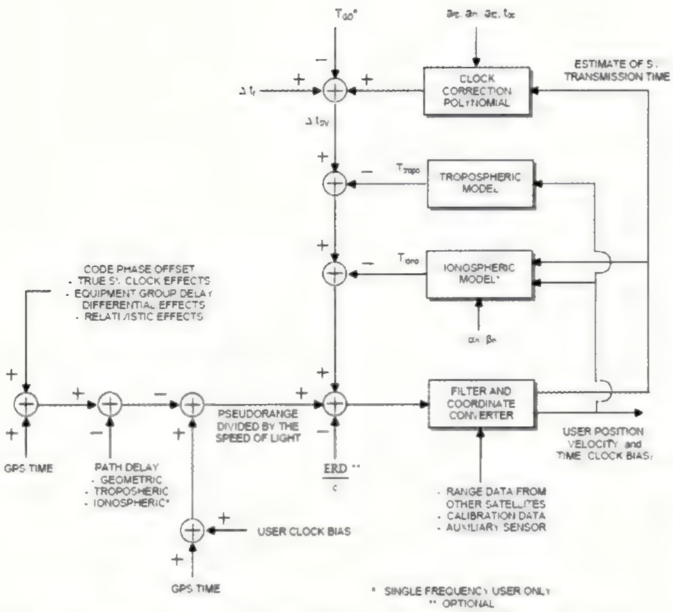


Fig.5: the mathematical model used by a GPS receiver to apply correction parameters. Similar procedures apply to other GNSS systems. SV stands for space vehicle; a10, a11 and a12 are polynomial coefficients related to satellite clock error; toc is "time of clock"; ERD is estimated range deviation; c is the speed of light; t is the true GPS time at the time of data transmission; t_{sv} is the space vehicle time; Δ_{tsv} is the difference between the space vehicle time and the centre of its antennae; Δ_{tr} is the relativistic correction; α and β are ionospheric parameters; T_{GD} is the group delay differential; and T_{tropo} and T_{iono} are corrections for tropospheric and ionospheric delays. *From Interface Specification IS-GPS-200K, "NAVSTAR GPS Space Segment/Navigation User Segment Interfaces".*

```
******** Week 512 almanac for PRN-24 ********
ID:                         24
Health:                     000
Eccentricity:               0.6661891937E-002
Time of Applicability(s):   319488.0000
Orbital Inclination(rad):   0.9505615234
Rate of Right Ascen(r/s):   -0.7850758266E-008
SQRT(A)  (m 1/2):           5153.627930
Right Ascen at Week(rad):   -0.7220151424E-000
Argument of Perigee(rad):   -0.651554227
Mean Anom(rad):             -0.5415329933E-000
Af0(s):                     0.1974105835E-003
Af1(s/s):                   0.3637978807E-011 week: 512
```

Fig.6: example almanac data for one satellite. Each GPS satellite transmits almanac data for all GPS satellites. This allows a receiver to determine which satellites are likely to be in view, significantly reducing the amount of signal searching that it needs to do.

```
EPHEMERIS FOR SATELLITE 24 :
PRN number for data .................. 24
Issue of ephemeris data .............. 179
Semi-Major Axis (meters) ............. 2.65599E+07
C(ic) (rad) .......................... -1.02445E-07
C(is) (rad) .......................... -1.22935E-07
C(rc) (meters) ....................... 168.656
C(rs) (meters) ....................... -63.3125
C(uc) (rad) .......................... -3.48687E-06
C(us) (rad) .......................... 1.1526E-05
Mean motion difference (rad/sec) ..... 3.94802E-09
Eccentricity (dimensionless) ......... 0.00623617
Rate of inclination angle (rad/sec) .. 1.05004E-10
Inclination angle @ ref. time (rad) .. 0.976756
Mean Anomaly at reference time (rad) . 1.79689
Corrected Mean Motion (rad/sec) ...... 0.000145861
Computed Mean Motion (rad/sec) ....... 0.000145858
Argument of perigee (rad) ............ -2.06498
Rate of right ascension (rad/sec) .... -7.67032E-09
Right ascension @ ref time (rad) ..... -2.4059
Sqrt (1 - e^2) ....................... 0.999981
Sqr root semi-major axis, (m^1/2) .... 5153.63
Reference time ephemeris (sec) ....... 252000
```

Fig.7: an example of GPS satellite ephemeris data, broadcast from each satellite. PRN is the pseudo-random noise number. The ephemeris is highly accurate orbital data from which the exact location of the satellite can be established.

on Earth would see the satellite clock running faster than an Earth-based clock by about 45μs per day.

The combined effect of the satellite clock running slower due to special relativity and faster due to general relativity from the point of view of an Earth-based observer is a difference of 38μs or 11.4km per day. Satellite navigation would therefore be worthlessly inaccurate if these relativistic effects were not taken into account

Another phenomenon that has to be taken into account is the kinematic "Sagnac effect". This can amount to a timing error of up to 207ns or up to 62m per day.

Between the satellite and the Earth, there is a rotating frame of reference. Two electromagnetic beams going in opposite directions on the same closed path around a rotating object will take different times to complete the trip. Therefore, the timing has to be adjusted to obtain the exact propagation time of a signal from the satellite to the receiver.

There are additional corrections which must be made to get accurate results, which will be discussed later.

The pseudo-random noise (PRN) ranging code

The pseudo-random noise code is what is used to identify which signals come from which satellites. All satellites in a GNSS constellation are assigned a unique PRN number.

In the case of GPS, two primary frequencies are used (with more under development). These are L1 and L2. Civilian GPS mostly uses just L1 (and some L2) and the military use both L1 and L2.

In the civilian case, since all satellites are broadcasting on the same frequency, a way is needed to identify the signal from each individual satellite from among a whole jumble of signals.

The GPS date rollover problem

GPS time uses week numbers which started counting at midnight on 5th January 1980 and are numbered from 0 to 1023 (ie, 1024 weeks), after which the week number is reset to zero. The first rollover occurred on 21st August 1999, and the next one after that was on midnight 6th April 2019.

The next rollover will occur at midnight on 2nd November 2038. This year, there was a concern that some GPS units might not handle the rollover correctly and would reset themselves to 1980 or 1999. People were warned about this, but it appears to have not been a problem as most GPS units were programmed correctly to handle it.

Editor's note: we noticed some older GPS modules giving incorrect dates after April 6. Apart from the date being wrong (nearly 20 years earlier than it should be), everything else seems to work, including location information and the time. These modules were purchased some years ago; those sold within the last few years should handle the week rollover seamlessly.

COMPONENTS OF EPHEMERIS DATA

Name	Description	Units
M_0	Mean anomaly at reference time	Semicircle
Δn	Mean motion difference from computed value	Semicircle/s
e	Eccentricity	Dimensionless
$\sqrt{a}$	Square root of semimajor axis	$m^{1/2}$
Ω_0	Longitude of ascending node of orbit plane at weekly epoch	Semicircle
i_0	Inclination angle at reference time	Semicircle
ω	Argument of perigee	Semicircle
$\dot{\Omega}$	Rate of right ascension	Semicircle/s
$IDOT$	Rate of inclination angle	Semicircle/s
C_{uc}	Amplitude of cosine harmonic correction term to the argument of latitude	Rad
C_{us}	Amplitude of sine harmonic correction term to the argument of latitude	Rad
C_{rc}	Amplitude of cosine harmonic correction term to the orbit radius	m
C_{rs}	Amplitude of sine harmonic correction term to the orbit radius	m
C_{ic}	Amplitude of cosine harmonic correction term to the angle of inclination	Rad
C_{is}	Amplitude of sine harmonic correction term to the angle of inclination	Rad
t_{0e}	Ephemeris reference time	s
$IODE$	Issue of data, ephemeris	Dimensionless

Parameter	Explanation
t_{oe}	Ephemerides reference epoch in seconds within the week
$\sqrt{a}$	Square root of semi-major axis
e	Eccentricity
M_o	Mean anomaly at reference epoch
ω	Argument of perigee
i_o	Inclination at reference epoch
Ω_0	Longitude of ascending node at the beginning of the week
Δn	Mean motion difference
$\dot{i}$	Rate of inclination angle
$\dot{\Omega}$	Rate of node's right ascension
c_{uc}, c_{us}	Latitude argument correction
c_{rc}, c_{rs}	Orbital radius correction
c_{ic}, c_{is}	Inclination correction
a_0	SV clock offset
a_1	SV clock drift
a_2	SV clock drift rate

Fig.8(a) [left]: the values within the ephemeris (orbital) data and their meanings. In addition to the ephemeris, the Navigation Message also contains the following important clock parameters: t0c (reference time) and a_0, a_1, a_2 (polynomial coefficients for clock correction: bias [s], drift [s/s], and drift rate/aging [s/s2]). Fig.8(b) [above] explains the symbols of Figs.8(a) and Fig.9

Fig.9 (opposite): for those interested in the mathematics behind calculating the satellite position using ephemeris data, here are the equations used. WGS84 is the World Geodetic System 1984 coordinate system, and ECEF is Earth-centred, Earth-fixed coordinate system. Table from Ryan Monaghan. *From:* siliconchip.com.au/link/aavl

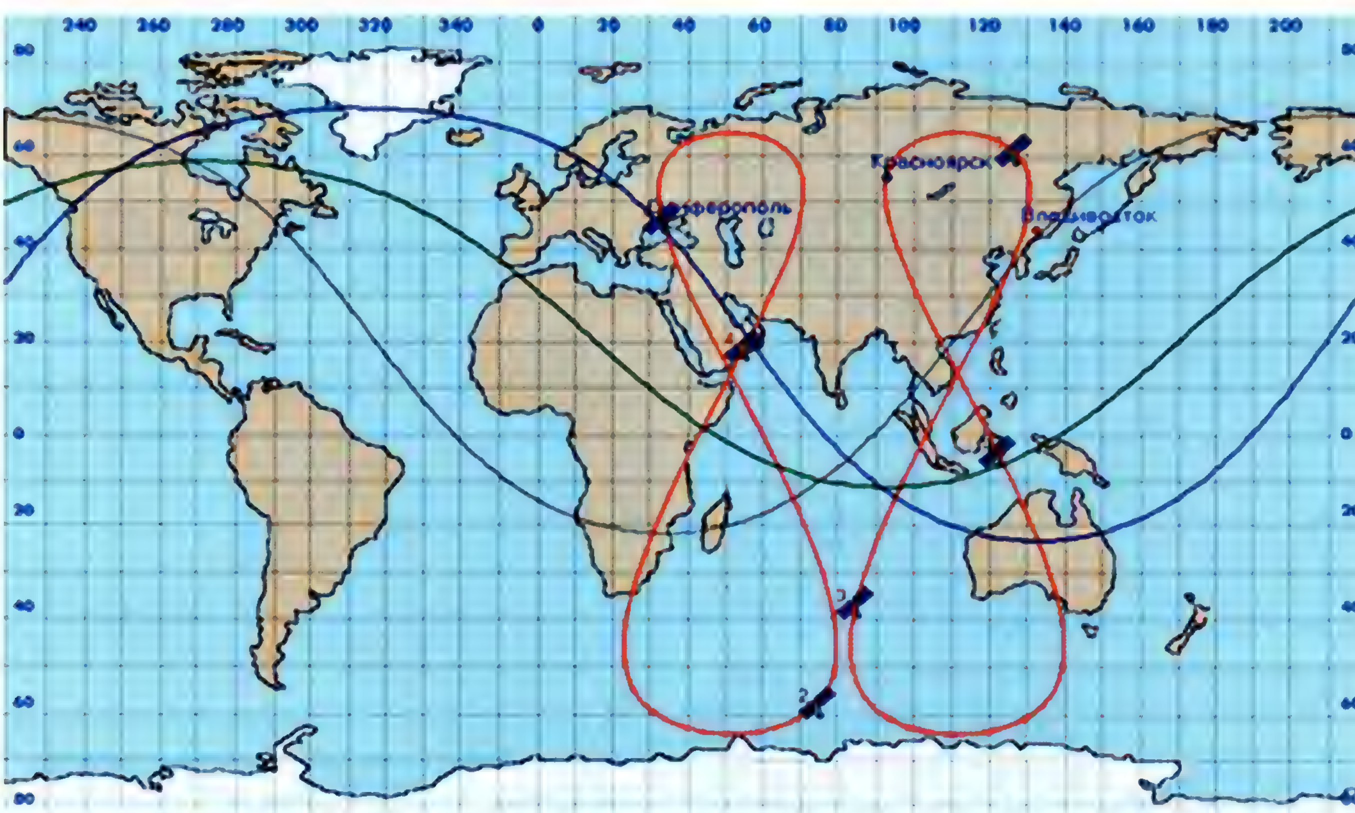


Fig.11: high-orbit GLONASS is a system that will be implemented to provide improved regional coverage over Russia, much like the Japanese QZSS system. The ground tracks of the orbits are shown in red. Presumably, Australian users will benefit from this system as with QZSS, as some of the satellites will be visible over Australia.

Algorithm For Computing Satellite Position

Equation	Description
$\mu = 3.986008 \times 10^{14} m^3 / s^2$	WGS 84 value of earth's universal gravitational parameter
$\dot{\Omega}_e = 7.292115167 \times 10^{-5} rad / s$	WGS 84 value of earth's rotation rate
$a = (\sqrt{a})^2$	Semimajor axis
$t_{n+1} = t - t_{0e}$	Time from ephemeris reference epoch
$f_n = \tan^{-1}\left\{ \frac{\sqrt{(1-e^2 \sin E_n /(1-e\cos E_n)}}{(\cos E_n - e)/(1-e\cos E_n)} \right\}$	True anomaly
$E_n = \cos^{-1}(\frac{e+\cos f_n}{1+e\cos f_n})$	Eccentric anomaly from cosine
$\phi_n = f_n + \omega$	Argument of latitude
$\delta\mu_n = C_{\mu C}\cos 2\phi_n + C_{\mu S}\sin 2\phi_n$	Second-harmonic correction to argument of latitude
$\delta r_n = C_{rC}\cos 2\phi_n + C_{rS}\sin 2\phi_n$	Second-harmonic correction to radius
$\delta i_n = C_{iC}\cos 2\phi_n + C_{iS}\sin 2\phi_n$	Second-harmonic correction to inclination
$\mu_n = \phi_n + \delta\mu_n$	Corrected argument of latitude
$r_n = a(1 - e\cos E_n) + \delta r_n$	Corrected radius
$i_n = i_0 + \delta i_n + (IDOT)t_n$	Corrected inclination
$x'_n = r_n \cos\mu_n$	*X* coordinate in orbit plane
$y'_n = r_n \sin\mu_n$	*Y* coordinate in orbit plane
$\Omega_n = \Omega_0 + (\dot{\Omega} + \dot{\Omega}_e)t_n - \dot{\Omega}_e t_{0e}$	Corrected longitude of ascending node
$x_n = x'_n \cos\Omega_n - y'_n \cos i_n \sin\Omega_n$	ECEF *X* coordinate
$y_n = x'_n \sin\Omega_n + y'_n \cos i_n \sin\Omega_n$	ECEF *Y* coordinate
$z_n = x'_n \sin i_n$	ECEF *Z* coordinate

CDMA (code division multiple access), a spread spectrum technique, is used to achieve this. CDMA was previously used on some mobile phone networks.

A PRN code is part of the CDMA scheme and is used to identify the signal of interest. It is a carefully selected binary code and one of a set. The PRN codes are chosen so that no two are alike.

The PRNs are called Gold codes after the person who invented them, and have "bounded small cross-correlations within a set" which means that they have the most possible difference between them (see Fig.3 & 4).

The PRN codes are predetermined and stored in both the satellites and receivers. By knowing the PRN code ahead of time, a receiver can pick out one signal from many that are simultaneously being received.

The PRN code is broadcast continuously, and the navigation data (at a much lower bit rate) is superimposed on that. The transmitted signal has more bandwidth than required for the transmitted navigation data, to allow the PRN code to be incorporated.

One way of thinking about this is like a room full of people all speaking different languages at the same time. If you are only interested in receiving the message of the speaker of one particular language (the desired PRN code),

Fig.10: a 10.23MHz rubidium frequency standard ("atomic clock") from the late 1970s, by Frequency Electronics, Inc. These were used on early GPS satellites, although this one looks more like a prototype. Part of the National Air and Space Museum collection, Smithsonian Institution, Washington DC.

the voices of all other speakers are rejected as noise (different PRN codes).

In the case of GPS, the PRN code is 1023 bits long and repeats every millisecond for civilian users. The military L1 and L2 signals have PRN sequences that are about 6.2 x 10^{12} bits long (773 gigabytes) and take one week to transmit, even at a higher bit rate (or chip as it is called).

The civilian PRN is known as the C/A code (coarse/acquisition) and the military the P (precision) code.

There is also a Y and a more modern M code for military use. These have improved anti-spoofing and anti-jamming capabilities.

There are also modernised civilian services on later satellites, on the L2 frequency (called L2 CM and L2 CL) which offer improved navigational accuracy and other benefits. "Safety of life" signals are also transmitted on more recent satellites on the L5 band, along with PRN ranging codes.

Apart from enabling multiple signals on one frequency,

The role of GPS in timekeeping

Apart from its obvious role in navigation, GPS also plays a vital role in timekeeping via the very accurate atomic clocks each satellite has onboard.

GPS can provide accurate time to within nanoseconds, compared to the old radio signals that provided millisecond accuracy.

Many industries use GPS timekeeping services to:

- provide a time stamp on transactional records
- keep mobile phone networks synchronised
- keep power grids synchronised
- keep digital broadcast services operating correctly, allowing efficient utilisation of limited radio spectrum bandwidth
- allow scientific instruments distributed over wide geographic areas, eg, seismometer networks utilising a common time reference... and for many other uses.

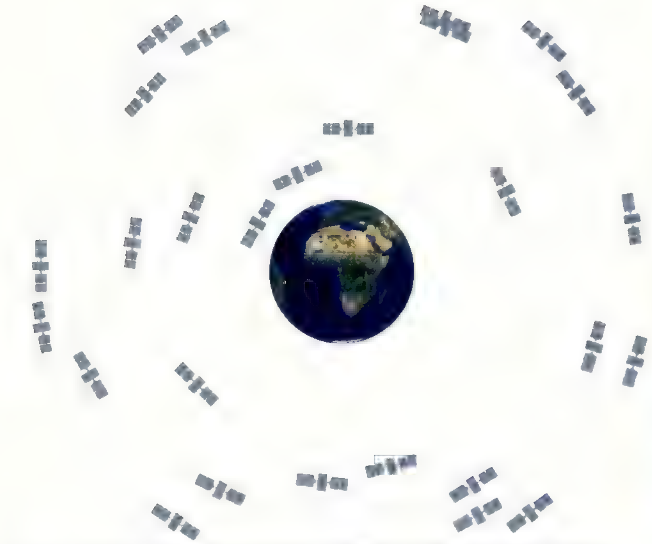
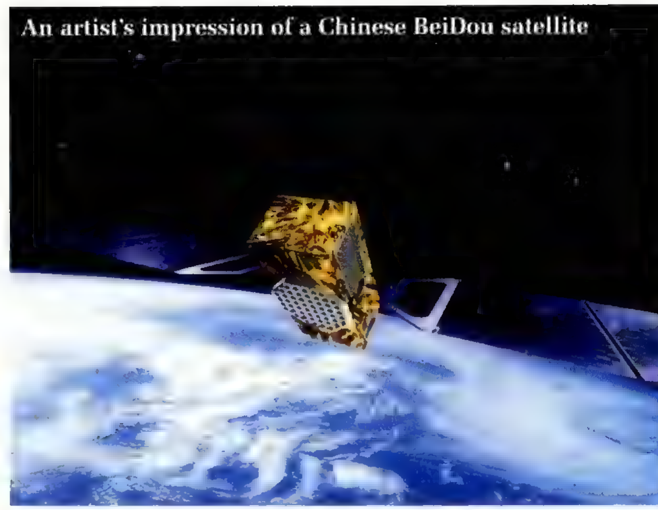


Fig.12: the arrangement of the GPS satellite constellation. The 24 satellites are in six equally spaced orbital planes and within each plane, there are four positions or "slots" occupied by satellites. This arrangement ensures that there are at least four satellites visible overhead at any point on the Earth's surface at all times.



An artist's impression of a Chinese BeiDou satellite

the CDMA technique allows for low transmission power and resistance to jamming and interference.

Applying time corrections

With the PRN code enabling the identification of individual satellites, and with knowledge of the PRN code expected at a particular time from that satellite in the receiver, it is possible to determine the offset between two matching segments of code and thus determine the approximate distance to a satellite. This distance is subject to corrections and thus called the pseudorange.

A typical receiver such as a hand-held unit, smartphone or in-vehicle navigation system does not have an atomic clock due to reasons of cost, size and power consumption. So the receiver is not precisely synchronised with the clock on the satellites, leading to uncertainty in the actual distance to the satellites.

The discrepancy between highly accurate clocks on the satellites and the less accurate clock at the receiver is resolved as follows.

The receiver gets signals from multiple satellites for a positional fix. The spheres representing the distance to three satellites will always intersect at two points (one of which is ignored), even if the clock receiver is wrong.

With a fourth satellite and a fourth sphere representing that satellite, there can only be one value of receiver time that satisfies the condition of the four spheres intersecting at one point.

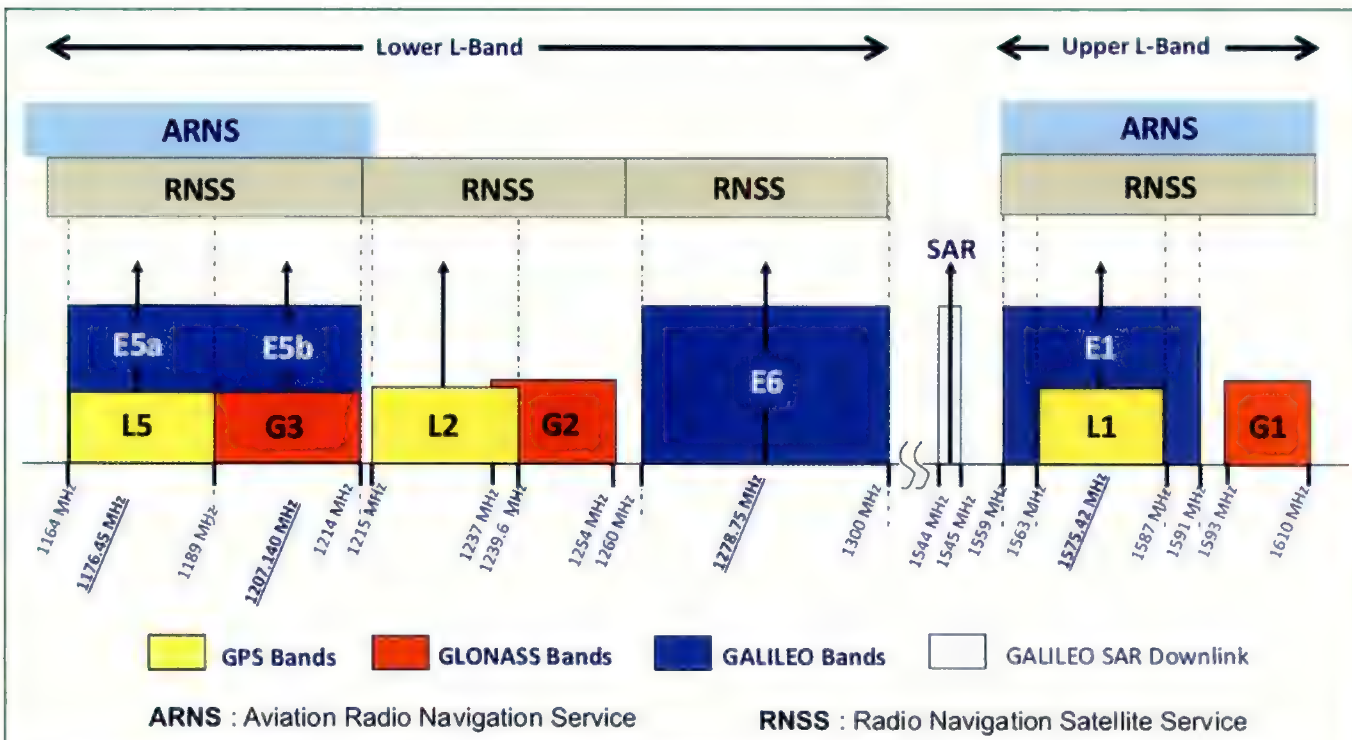
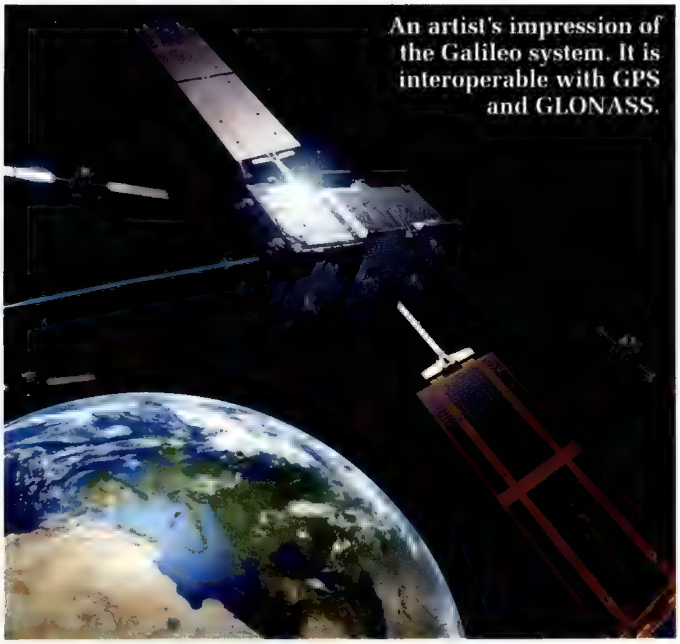


Fig.13: a comparison of GPS, GLONASS and Galileo frequency bands as well as some other frequency allocations. BeiDou is not included in this diagram. Note several areas of overlap.



An artist's impression of the Galileo system. It is interoperable with GPS and GLONASS.

The receiver adjusts its clock to that value, thus ensuring it is synchronised to the atomic clocks of the satellites. It must do this constantly due to the inherent inaccuracy in the receiver clock.

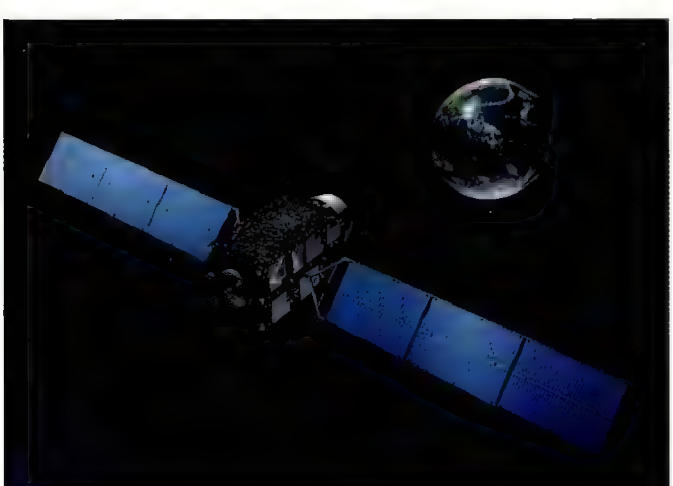
Further corrections

There are signal delays caused by the passage of signals through the ionosphere, leading to an error of about 83ns or 25m. Passage through the troposphere leads to an additional 7ns or 2m error.

Other effects taken into account either on the satellite or user equipment are the space vehicle clock error due to bias, drift, ageing and group delay (the time delay as a function of frequency for a signal to go through the electronics of the satellite).

A detailed flow chart for the process is shown in Fig.5. As can be seen, the process involves calculating the satellite clock bias, group delay, relativistic and other effects; accounting for delays due to the atmosphere and geometric effects and then correcting pseudorange to give the Estimated Range Deviation (ERD) due to these timing effects.

But there are still more calculations that need to be made



An artist's impression of a QZSS satellite in orbit.

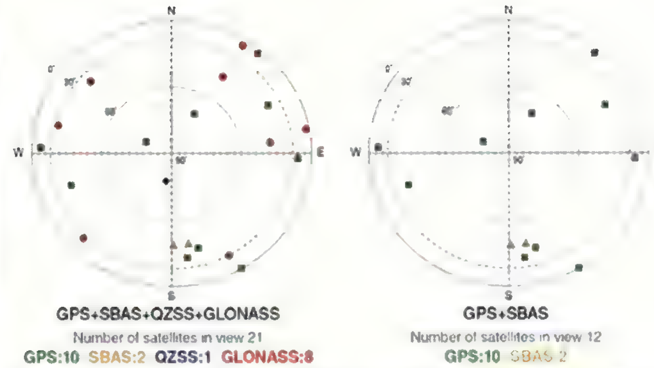


Fig.14: an example of satellites visible from Furuno's multi-GNSS receiver, compared to their GPS-only receiver. SBAS stands for Satellite Based Augmentation System.

to determine the receiver position.

Establishing the position of the satellites

We now have explained how the pseudorange is obtained and how this is adjusted to get the exact propagation time of the radio signals from the satellite to the receiver. We still have not established the positions of the satellites from which we can determine a navigational fix, and that is the next task. All GNSS systems work similarly but we will look at GPS as an example.

A GPS satellite transmits both an almanac (Fig.6), which has general positional data for all satellites in the constellation, and an ephemeris (Fig.7), which is accurate orbital data specific to itself. Almanac data gives information about what satellites are in the area of view of the receiver, so that it doesn't have to spend extra time looking for satellites that are not visible.

Almanac data is considered valid for about 180 days, while ephemeris data is valid for only about four hours. Ephemeris data allows the exact location of a satellite to be established at a given time, and takes into account perturbations due to gravitational influences on the satellite from bodies such

A ground track of one of Japan's QZSS satellites, showing that most of Australia is included in its coverage area. This effectively adds four GPS-compatible satellites.

DIY GNSS Projects

GPS modules can be purchased from the SILICON CHIP ONLINE SHOP. If you can afford to wait, they're also available quite cheaply on line, for as little as $5 delivered.

SILICON CHIP has published many projects using inexpensive GNSS modules for purposes such as clock and frequency references, or most recently as an accurate speedo and automatic vehicle audio volume controller (June 2019). See: www.siliconchip.com.au/project/gps

Here are online articles explaining how to interface these modules to Arduinos, Raspberry Pis and other similar platforms.

- To connect to a GNSS module to a PC, you need a USB/serial converter. Make sure it is the correct voltage for the module, usually 3.3V. Note that some converters won't work with Windows 10; the CP2102-based modules in our Online Shop are relatively trouble-free.
- A popular GNSS module brand is u-blox. They make the VK2828U7G5LF modules sold in our ONLINE SHOP (Cat SC3362). They have free evaluation software that allows you to see many aspects of GNSS operation with their modules.
- See: siliconchip.com.au/link/aavm (Windows software). A suitable Arduino library called TinyGPS++ is at: siliconchip.com.au/link/aavn
- See the videos titled *"Playing with GPS: Ublox Neo-7M and U-Center"* at: http://siliconchip.com.au/link/aavo and *"10Hz U-blox binary GPS data in 66 lines of code (Arduino)"* at siliconchip.com.au/link/aavp
- You can see the position of various GNSS or other satellites in the sky at: siliconchip.com.au/link/aavq
- Build a geocaching pendant as described at: siliconchip.com.au/link/aavr
- RTKLIB (www.rtklib.com) is an open-source program for high-precision GPS with low-cost devices. See also: http://rtkexplorer.com/

as the sun and moon.

Ephemeris data includes the standard six Keplerian elements, plus ten others, to take into account minor influences which affect the satellite's orbit.

The orbit of a satellite can be determined using the laws of physics plus minor deviations from theory due to unknown random forces, which are determined with ground-based radar, providing corrections incorporated into the ephemerides (the plural of ephemeris). Fig.8 shows the meanings of the ephemeris parameters, while Fig.9 shows the calculations involved.

The coordinate system

Once a GNSS system has established the receiver position, it still needs to be placed on a particular reference frame. The Earth is not a sphere but rather an "oblate spheroid" of 6,378,137m x 6,357,002m.

Various standard reference frames have been developed for navigation that correctly place coordinates on the Earth's true surface.

Typically, WGS84 (World Geodetic System) is used for

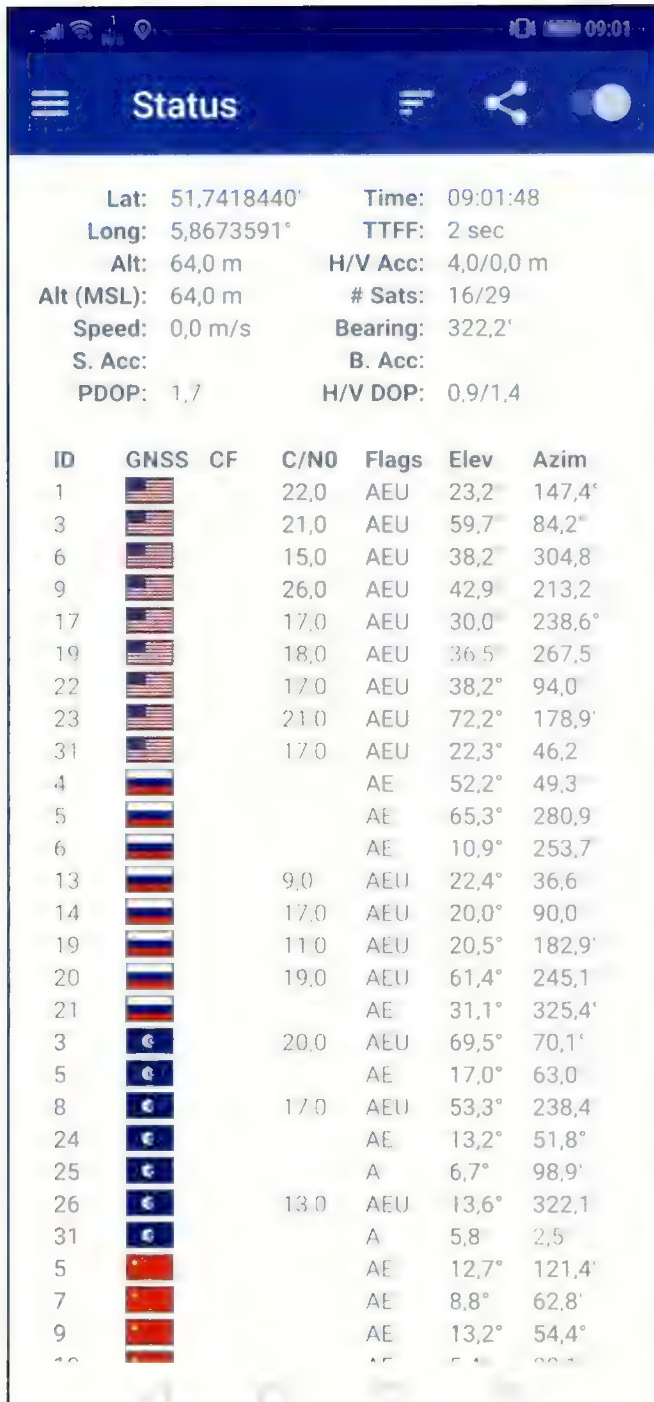


Fig.15: a screen grab of the GPSTest App for Android showing satellites visible on the phone's GNSS receiver. From top to bottom, the constellations are GPS, GLONASS, Galileo and BeiDou.

GPS for the so-called Earth-centred, Earth-fixed (ECEF) reference frame. In Australia, the standard reference frame for high precision work is the Geocentric Datum of Australia, GDA94 but as Australia drifts north due to tectonic plate movements, this is now out by 1.6m.

GDA2020 is under development; WGS84 still gives acceptable results for most users.

The atomic clocks

GNSS systems would not be possible without the use

Comparison of satellite navigation systems

	GPS	GLONASS	Galileo	BeiDou
Country	USA	Russia	EU	China
Number of satellites as of 18 June 2019	total: 32 31 operational 1 in maintenance	total: 27 24 operational 1 in commissioning 1 spare 1 in testing	total: 30 26 operational 4 to be launched (3 of which are spares)	total: 39 33 operational 6 non-operational 35 to be operational by 2020
Altitude	20180km	19130km	23222km	21150km for medium Earth orbit satellites (MEO)
Frequencies used	L1: 1575.42MHz L2: 1227.60MHz L3: 1381.05MHz L4: 1379.913MHz L5: 1176.45MHz (L1 and L2 are the primary frequencies, others are little used or experimental)	Modernised: L1: 1600.995MHz L2: 1248.06MHz L3: 1202.025MHz For future interoperability with other systems: L1: 1575.42MHz L3: 1207.14MHz L5: 1176.45MHz	E1: 1575.420MHz E6: 1278.750MHz E5: 1191.795MHz E5a: 1176.450MHz E5b: 1207.140MHz	B1I, B1Q: 1561.098MHz B1C, B1A: 1575.42MHz B2B, B2I, B2Q: 1207.14MHz B2a: 1176.45MHz B3I, B3Q, B3A: 1268.52MHz
Signal encoding	CDMA	FDMA but moving to CDMA	CDMA	CDMA
Orbital period	11h 58m (half a sidereal day)	11h 15m	14h 7m	For 27 satellites in MEO: 12h 37m
Orbital regime	6 planes in medium Earth orbit	3 planes separated by 120°, 8 satellites in each plane; satellite inclination 64.8°	27 operational satellites in 3 planes with 56° inclination to the equatorial plane	For 2020: 5 geostationary 3 inclined geosynchronous 27 Medium Earth orbit
Accuracy	300-5000mm	2.8-7.38m, next-generation GLONASS-K2 from 2019 is intended to reduce user range error to 300mm	1m public 10mm restricted	10m public (global) 5m Asia Pacific region 100mm restricted
First in service	First launch: 1978 Initial operational capability: December 1993. Fully operational: April 1995	Claimed fully operational in December 1995 but not globally available until the mid-2000s	Completion by end 2020 but operational now	Completion by end 2020 but some services available since December 2012

of extremely accurate atomic clocks. As mentioned above, radio signals travel 30cm in one nanosecond, so clock accuracy has to be of that order or better to obtain a good navigational fix.

GPS satellites have four onboard cesium and rubidium atomic clocks. These are kept in sync and are adjusted by even more accurate Earth-based atomic clocks. Typical accuracy of the clock on the latest GPS satellites is ±4 nanoseconds, representing about ±120cm of range error.

We published an article in the February 2014 issue which explained how rubidium atomic clocks work (siliconchip.com.au/Article/6127).

GNSS receiver start-up

A receiver usually cannot get a position fix as soon as it is powered up. There are three distinct start-up situations which lead to differing power-on times before a fix can be made.

If the receiver is brand new or hasn't been used for a long time, that makes it a 'cold start'. The receiver doesn't know where it is, so it has to search for all possible satellites. After a satellite is acquired, it then has to download the almanac data for all satellites. This takes 12.5 minutes and gives it the approximate positions of the other satellites.

A 'warm start' is where the receiver already knows the time within 20 seconds and its position within 100km and

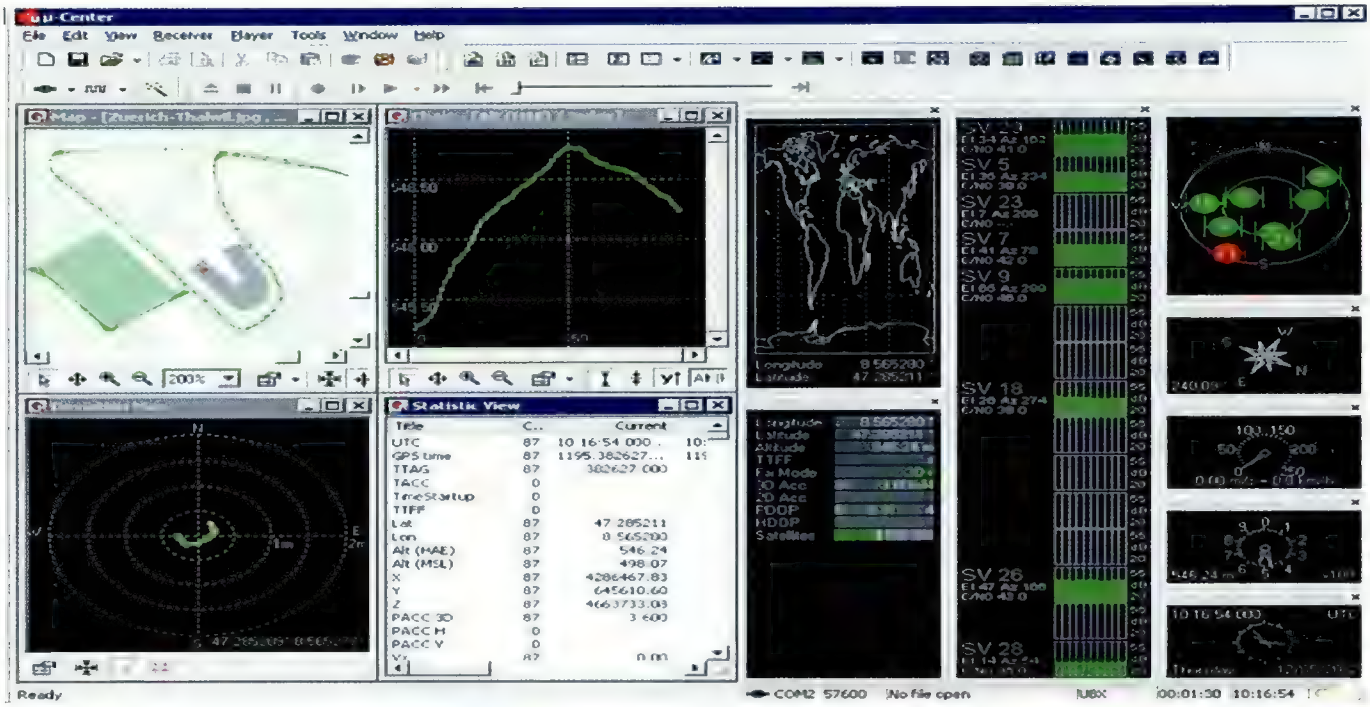


Fig.15: an example of the free u-center evaluation software for Windows, which allows inexpensive u-blox GNSS modules to be tested and configured. See siliconchip.com.au/link/aavm

has current almanac data.

It can then find the ephemeris data for at least four satellites, which is broadcast every 30 seconds, and then get a positional fix, usually within a minute.

A 'hot start' is where the receiver has current time, almanac, ephemeris, and position to allow rapid acquisition of new signals, usually within a few seconds. Vehicle GPS systems which can be "always on" may use this system.

Some GNSS systems used in Smartphones can sometimes start faster, because in addition to the GNSS location, they also use a database of WiFi network locations to help determine their location earlier than the GNSS signal would permit.

GPS and leap seconds

The global time standard is UTC or Coordinated Universal Time. Since the Earth's rotation rate varies naturally by a slight amount, every so often a leap second is added or removed to keep Univeral Coordinated Time synchronised with the Earth's rotation.

The leap second is not implemented in GPS because of the navigational errors and confusion this would cause. The difference between UTC and GPS time was zero when the GPS clock started on 1st January 1980, but is now 18 seconds.

The GPS Navigation Message broadcasts the difference between UTC and GPS time, so a receiver can show the correct UTC or local time.

Mapping errors

Finally, note that while a GNSS fix is generally extremely accurate, the maps used by navigation systems are not necessarily accurate.

There have been many mishaps due to people following incorrect maps, only to become stranded, or in some cases, driven over cliffs or off the end of piers! This is, of course, a problem of the maps and not the GNSS system itself.

To help ensure the most accurate possible and free maps the public can contribute to the production of open-source maps by joining the OpenStreetMap community (www.openstreetmap.org).

Some maps contribute to specialised interests such as four-wheel-driving, mountain biking, bush walking, etc, while others concentrate on regular street navigation. SC

Mixing and matching multiple GNSS systems

Many modern satnav receivers can decode GPS, Galileo, GLONASS and QZSS (Japan's regional system) signals. An increasing number of devices can also decode BeiDou.

Multi-GNSS receivers have improved performance due to the greater number of satellites in view, especially in urban canyons where the view of the sky is very limited.

You can see what systems your Android smartphone can receive with the free GPSTest App. Note that QZSS, which is visible in most of Australia with standard GPS receivers, effectively adds four more satellites to the constellation

Novel wearable GPS products

One of the more special GPS products we have seen is the GPS SmartSole, a GPS unit built into the sole of any shoe that connects to the mobile phone network. It can be used to track loved ones with memory disorders.

See: siliconchip.com.au/link/aavs

Their tracking services are available in the USA only.

They do not mention whether it is compatible with a shoe phone, so if you are hot on the heels of a KAOS agent, you had better do your own testing!

And now . . .
the perfect partner for our AM receiver:

By John Clarke

The Super-9 FM Radio

This FM radio is easy to build and provides excellent performance. An entirely analog design, it has a sizeable internal speaker, with the ability to drive stereo headphones or external speakers. It can be battery or mains powered and is tuned with a hand-span dial. It looks great in its custom case, and building it is an excellent way to learn how FM radio works.

Our **"Super-7" AM Radio (November & December 2017)** has proven to be very popular. So we've developed this high-quality FM Radio with many of the same features. That includes ease of construction, good looks and great performance. It takes full advantage of the high audio quality that FM broadcasts are capable of reproducing. And it can receive in stereo, too.

It's powered from a 9V battery (making it truly portable) or 9V DC plugpack, and it automatically switches from battery to the plugpack when plugged in. Power consumption is moderate, so a small 9V battery should last for several hours of listening.

All the components mount on one double-sided PCB (printed circuit board) which fits into a custom-designed acrylic case with a transparent back. That's so the components are protected but you can still see its workings. It has a large hand-span tuning dial showing the current frequency plus many of the available FM radio stations around Australia.

Once built and aligned, you will have a fully functioning radio. And that's something the average person with basic soldering skills can do, as long as you follow our instructions. Besides the usual soldering and mechanical assembly using screws, nuts and spacers, you just need to wind a few coils.

This FM Radio would make a great learning aid for people studying electronics. Most modern FM receivers use one or two integrated circuits (ICs), with a few external components.

However, for this design, we have opted for a more discrete approach, so that the major circuit blocks are all clearly separated.

Although we have used a few ICs, each only performs one or two major tasks. The circuit is therefore discrete in the sense that each functional block is separate, and that makes it easy to understand what it does and how it works.

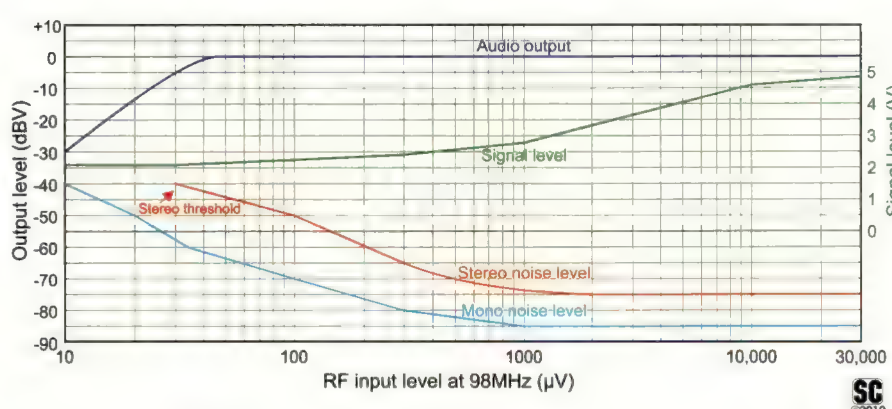
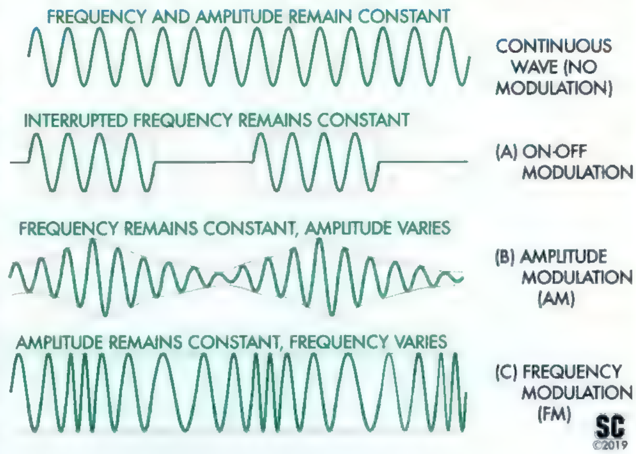


Fig.1: these curves show how the unit's performance varies with signal strength. The blue "Audio output" curve shows the test tone output level, with the cyan and red curves showing the corresponding noise levels. The distance between the Audio output and mono/stereo noise level is the signal-to-noise ratio for that input level. The corresponding voltage at TP SIGNAL is also shown in green, using the right-hand axis. Full limiting does not occur until the RF input reaches about 45µV, while stereo cuts out below 30µV.

Receiver

What is FM?



Going back to the times when radio was discovered, there have been three basic methods of encoding a radio frequency wave, or "carrier", with information.

The first of these is CW, or **continuous wave**. If the RF carrier is fixed at one particular frequency and the level, or amplitude, is held constant, the only way that information can be conveyed is by switching the RF signal on and off. This is the technique used for Morse Code and other types of digital transmission, as shown in (A).

Next to come was called **amplitude modulation**, or AM. Here a second signal is modulated, or mixed, with the radio carrier, which causes the RF signal level to vary in sympathy with the second signal. This makes it is possible to transmit speech, music or even video. This is shown in (B).

A receiver that's tuned to the carrier frequency can detect these changes in amplitude to reproduce the varying signal. But this type of encoding is quite prone to interference. Part of the reason for this is that the signal amplitude necessarily dips at times, and at these points, it can be more easily overwhelmed by interfering signals. Also, any distortion of the carrier waveform distorts the signal.

The third method is called **frequency modulation** (FM). Instead of varying the carrier amplitude, information is conveyed by varying the carrier frequency, again in sympathy with the incoming speech, music or video signal. This is shown in (C). Note that the waveform amplitude is constant. At the receiver, the variations in carrier frequency are detected (or demodulated) to recover the original signal.

Any variations in amplitude that may occur in the received signal are effectively ignored. Therefore, FM receivers are far less prone to interference than their AM counterparts.

Broadcast band FM transmitters modulate the RF carrier by a maximum of 75kHz above and below the carrier frequency, which is typically around 100MHz. They also include pre-emphasis, whereby audio signals above 3.1831kHz (50μs time constant) are boosted. These signals are subsequently restored to normal in the receiver using a complementary de-emphasis circuit.

The idea behind using pre-emphasis and de-emphasis is to reduce high-frequency noise, which may be injected by the modulating/demodulating circuitry or by interfering signals. By boosting high frequencies before transmission, then cutting them after reception, any high-frequency noise picked up along the way is also significantly attenuated.

The radio is aligned with the aid of a simple 10.7MHz oscillator, which you can also easily build yourself. Along with the FM Radio construction details, we'll have a project for one of these next month.

Apart from that, the only other items required for alignment are a multimeter and a plastic trimming tool.

These days, many components are only available in surface-mounting packages. Some of those can be quite tricky to hand-solder.

We have done our best to use mainly through-hole components in this Radio, but in some cases, we had no choice. However, those few SMDs we've had to use can be soldered without too much difficulty, since they only have a few pins and the pins are not that closely spaced.

Radio performance

The performance of this FM Radio is shown in Fig.1 and described in the Features & Specifications panel.

The minimum usable RF signal level is around 35μV, at which point the audio signal level is about 3dB down. With 100μV from the antenna, the mono signal-to-noise ratio is 70dB, which is quite good.

The ultimate signal-to-noise ratio in mono is 85dB (ie, with a sufficiently strong signal). Few commercial tuners would match that. The ultimate stereo signal-to-noise figure is 75dB, also very good.

So while this is not the most sensitive FM Radio ever devised, it provides excellent performance on all local stations, with good reception for signals up to, say, about 70km away. In fact, this FM Radio sounds better than all but the best commercial receivers (and probably most FM receivers made in the last 10 years or so).

Before you read the description below of how the FM Radio works, you may wish to first refresh your knowledge of FM Radio by reading the explanatory panel at left.

Block diagram

The Super-9 Stereo FM Radio is based on the superheterodyne principle. Fig.2 shows its general configuration.

The antenna at upper left picks up signals in the FM band. These signals are fed to a bandpass filter, a parallel resonant circuit comprising one inductor (L1) and two capacitors. These heavily attenuate signals outside the 88-108MHz FM broadcast band.

These signals then pass to a tuned RF amplifier stage. This stage has a parallel resonant circuit that is tuned by inductor L2 and varicap diode VC1.

VC1 has a capacitance that changes with applied voltage. By adjusting the applied voltage, the RF amplifier can be tuned to any nominal frequency from 88 to 108MHz.

Therefore, it only amplifies signals at the desired frequency and attenuates the rest.

The tuning voltage comes from a tuning potentiometer (VR1), and the voltage is processed in the control voltage circuit to provide the required range for VC1 to tune over the broadcast band.

Following the RF amplifier, the signal is fed to the mixer (Q2 & T1), where it is mixed with the local oscillator signal. This tracks the tuned RF amplifier frequency, which is achieved using a second varicap diode (VC2) in combination with inductor L3. The local oscillator tracks 10.7MHz below the tuned RF signal carrier. In other words, it is adjustable from 77.3MHz to 97.3MHz.

So for example, if the FM Radio is tuned to 102.5MHz, the local oscillator will be at 91.8MHz (102.5MHz

Features & specifications

Tuning range: .... 88-108MHz (FM broadcast band)
50dB quieting sensitivity: 20µV
Signal-to-noise ratio: .... 85 dB mono, 75dB stereo with 150mV input (see Fig.1)
Distortion (mono): .... 0.39% @ 1kHz, 100% deviation; 0.31% @ 1kHz, 75% deviation; 0.8% @ 6kHz, 75% deviation
Distortion (stereo): .... 0.7% @ 1kHz, 75% deviation; .7% @ 6kHz, 75% deviation
Frequency response: .... 30Hz-20kHz, +0,-1dB with 150Ω load (-3dB at 27Hz with 32Ω load)
Demodulator output: .... 190mV RMS for 100% deviation at 1kHz
De-emphasis time constant: ... 50µs
Frequency capture range: .... ±200kHz
Operating voltage range: .... 9-12V DC
Current consumption: .... 75mA @ 9V with low volume

- 10.7MHz). The 10.7MHz frequency difference is a standard value for broadcast-band FM receivers.

Tuning of this oscillator is also via VR1, with the control voltage for VC2 processed in the same control voltage block, to provide the required tuning range.

The local oscillator frequency is fine-tuned (to ensure the correct 10.7MHz gap) via the automatic frequency control (AFC) signal from the demodulator block (described below).

This produces a voltage that controls the capacitance of varicap VC3, which is connected to the local oscillator. AFC is voltage feedback to keep the local oscillator in-lock with the tuned signal, so the FM Radio does not drift off station.

This also produces a snap-in effect, whereby the station suddenly locks in as the tuning approaches the station frequency.

Note that the tuned amplifier is not affected by AFC. However, the RF stage bandwidth is sufficiently broad that it does not need to track precisely with the local oscillator.

Superheterodyning of the two signals takes place in the mixer. By the way, the word "heterodyne" refers to a difference in frequency or beating effect, while the "super" prefix refers to the fact that the beat frequency is supersonic or ultrasonic (ie, beyond the range of human hearing).

Four signals are produced as a result of mixing the tuned and local

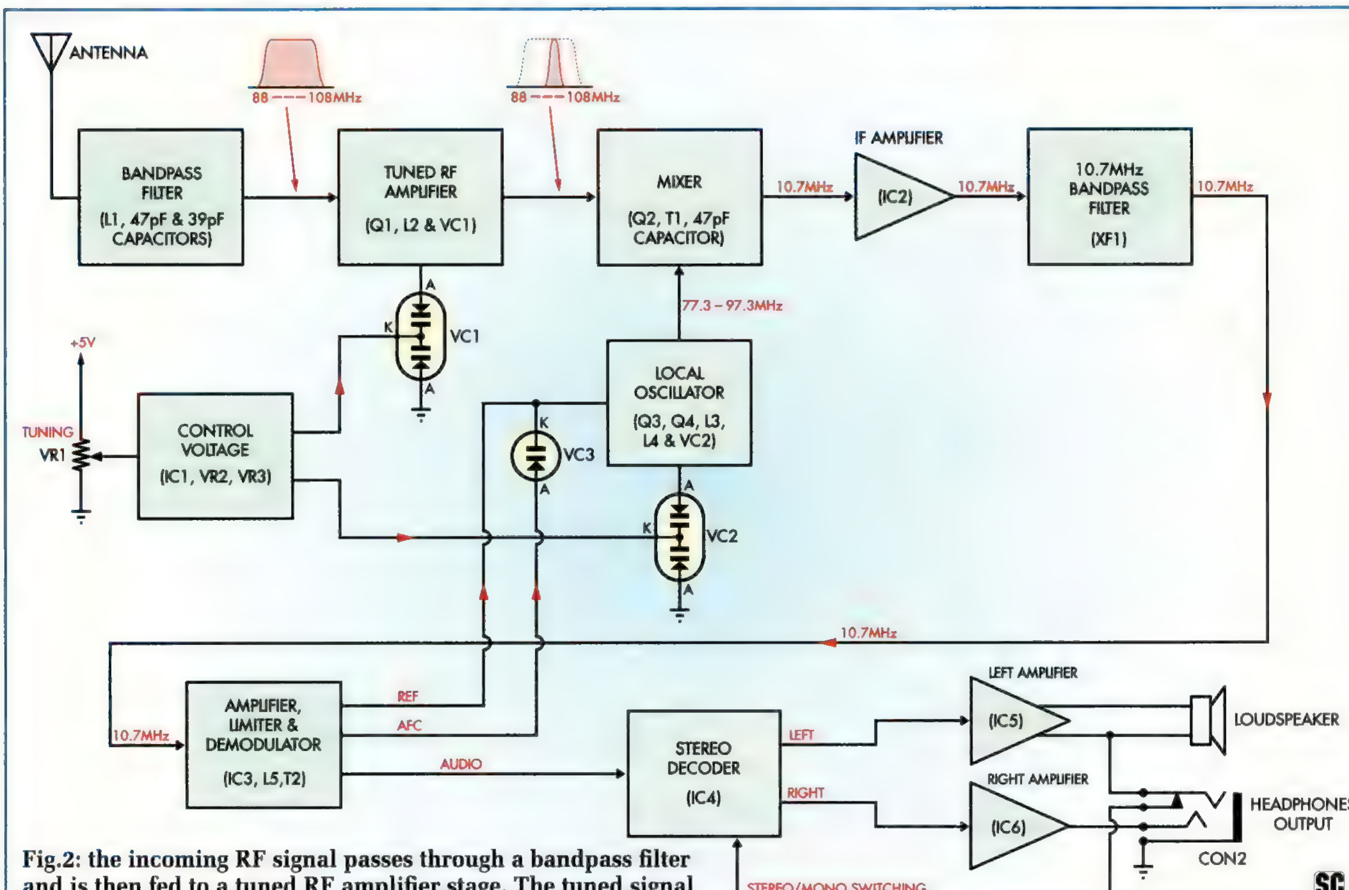
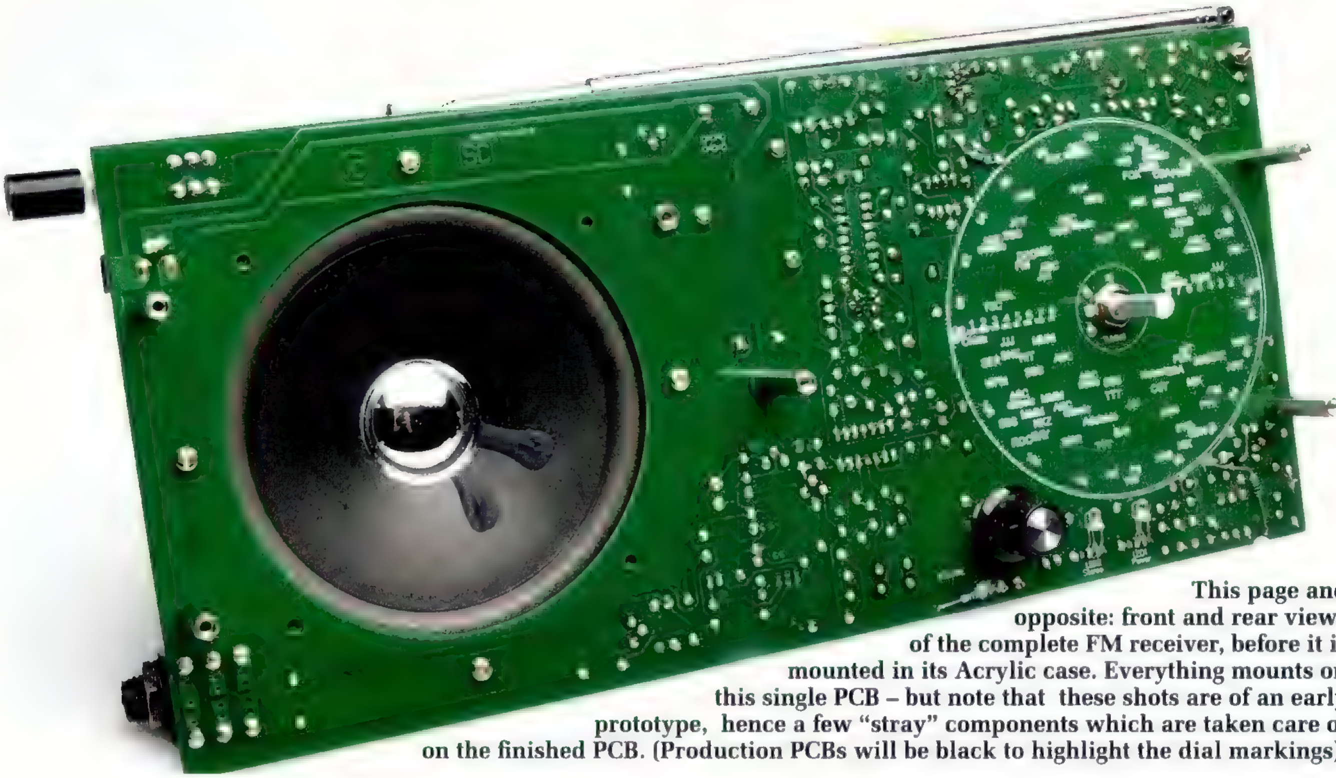


Fig.2: the incoming RF signal passes through a bandpass filter and is then fed to a tuned RF amplifier stage. The tuned signal is then mixed with the local oscillator signal to produce a 10.7MHz IF signal. This is then further amplified, filtered and fed to the demodulator. A stereo decoder and amplifiers for the left and right channels provide stereo for headphones and mono drive for the in-built loudspeaker.



This page and opposite: front and rear views of the complete FM receiver, before it is mounted in its Acrylic case. Everything mounts on this single PCB – but note that these shots are of an early prototype, hence a few "stray" components which are taken care of on the finished PCB. (Production PCBs will be black to highlight the dial markings).

oscillator signals. These comprise the two original signals and the sum and difference frequencies. One of these is @ 10.7MHz ±75kHz, due to the fixed difference between the RF carrier and local oscillator.

The mixer output is fed to a bandpass filtering comprising transformer T1 and a 47pF capacitor. This filter is tuned for a centre frequency of 10.7MHz, so it rejects the other three signals and just keeps the 10.7MHz difference signal. This then passes to an amplifier stage, providing a gain of about 60 times (53dB).

A much sharper-edged bandpass filter follows, which prevents signals passing through outside of a 280kHz band centred at 10.7MHz (ie, 10.7MHz ±140kHz).

The big advantage of producing a fixed frequency signal to process is that we now only need to provide further gain at one frequency, rather than for the whole 20MHz broadcast band range, which would require complicated tracking filters.

The amplifier, limiter and demodulator block includes a three-stage amplifier for this IF signal, to ensure that this signal is driven into limiting.

Limiting

Limiting is where the amplification factor is so high that the signal is clipped to the same level, even with a greatly varying input signal level.

This is done to eliminate any amplitude variations in the tuned signal before it is fed into the demodulator. This is one of the factors that enables FM tuners to reject atmospheric and electronic noise that mainly affects RF signal amplitude.

The amplifier, limiter and demodulator block also provides the AFC signal (mentioned above) and the audio signal output. This is obtained using a quadrature detector comprising inductor L5 in series with a tuned circuit with variable inductor L6 and a parallel capacitor.

This tuned circuit is adjusted to resonate at 10.7MHz. The inductor produces a fixed 90° phase shift while the tuned circuit provides an additional leading or lagging phase shift with frequency. A mix of these signals then produces a varying voltage that is the audio output.

Stereo decoding

Most FM radio stations broadcast in stereo for separate left (L) and right (R) channels. This is done by encoding the sum (L+R) and difference (L–R) signals in the FM transmission using a 38kHz subcarrier. This is shown in Fig.3.

For mono reception, just the L+R signal is used. Since the left and right channels are the same for a mono signal, the L+R will be the same as 2L.

For stereo reception, the left channel is derived as the sum of L+R and L-R (giving 2L) and the right channel is the difference of L+R and L-R (giving 2R).

The left and right channels are decoded using a 19kHz pilot signal, which is exactly half the frequency of the 38kHz suppressed subcarrier. The phase of the pilot signal allows the left and right sum and difference signals to be decoded.

Fig.3 shows the FM stereo encoding

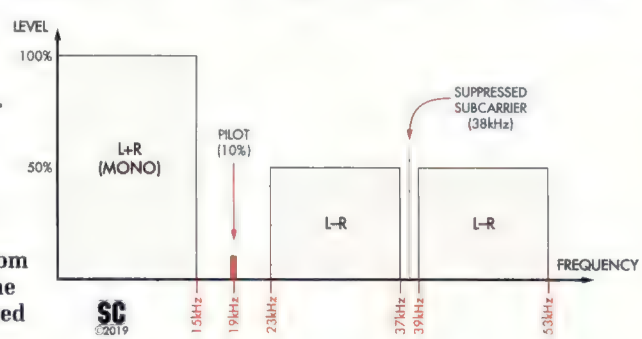


Fig.3: the FM stereo encoding scheme, with the L+R signal extending out to 15kHz. The pilot signal at 19kHz is 10% of full modulation. The L-R signal is from 23kHz to 38kHz (a 15kHz bandwidth) and also from 38kHz to 53kHz with the 38kHz carrier suppressed (ie, not transmitted).

with the L+R signal extending out to 15kHz. The pilot signal at 19kHz is just 10% of the full modulation. The L-R signal is from 23kHz to 38kHz (a 15kHz bandwidth) and also from 38kHz to 53kHz with the 38kHz carrier suppressed (not transmitted).

The audio signal is processed in the stereo decoder (IC4) that separates the audio into left and right channels. This also includes the necessary 50µs de-emphasis to compensate for the pre-emphasis in the transmitted signal. Amplifiers IC5 and IC6 provide the stereo signal output to drive headphones.

Stereo decoding occurs only when headphones are connected — switch contacts within the headphone socket control whether there is stereo or mono output from IC4. Without the headphones connected, the sound is from the single loudspeaker in the Radio, so reception is in mono. Audio amplifier IC5 drives the loudspeaker.

Circuit details

Refer now to Fig.4 (overleaf) for the full circuit of the Super-9 Stereo FM Radio. Its main components are dual-gate Mosfets Q1 and Q2, high-frequency transistor Q3, video amplifier IC2, amplifier/limiter/demodulator IC3, stereo demodulator IC4 and audio amplifiers IC5 and IC6.

The function of each stage is shown on the circuit, and each stage can be directly related to the block diagram (Fig.2).

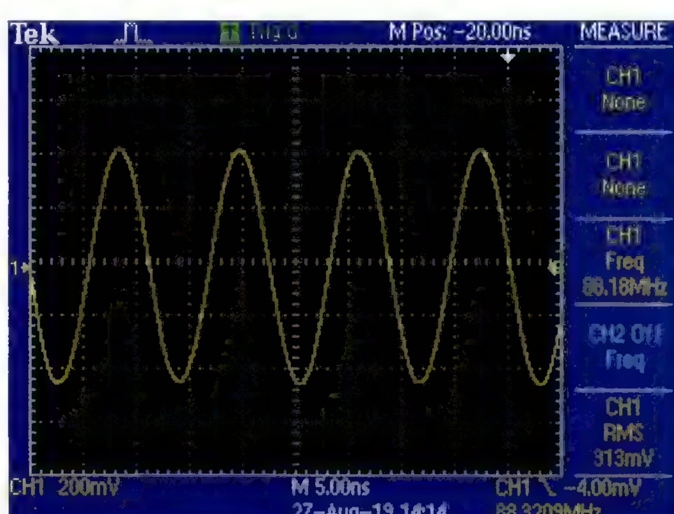
Starting at the antenna, the incoming RF signal is coupled to the junction of two capacitors (39pF & 47pF) which, together with parallel inductor L1, form the input bandpass filter. A 1kΩ resistor is included in parallel with L1 to reduce the filter Q, so that it covers the entire FM band without adjustment.

This input filter helps to prevent signals with frequencies outside the FM band from entering the circuit and possibly overloading the following stages.

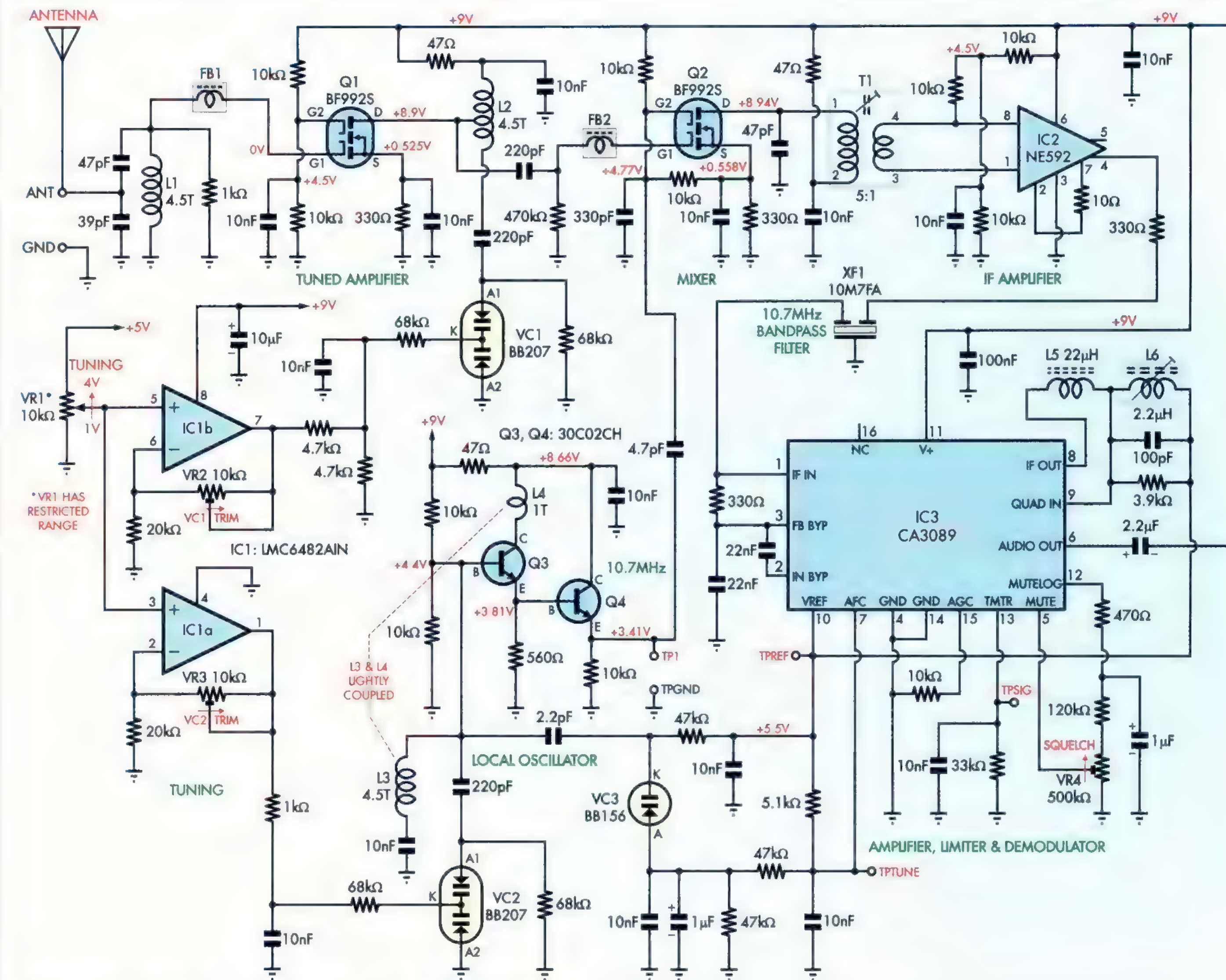
Following the input filter, the RF signal is fed via ferrite bead FB1 to one gate (G1) of dual-gate Mosfet Q1. Q1 operates in a common-source configuration. Its quiescent current is set by the 330Ω source resistor, bypassed by a 10nF capacitor to ensure maximum AC gain.

The gain is set to a high value by biasing G2 above its cut-off voltage, at around 4.5V, by the two 10kΩ bias resistors connected in series across the 9V supply.

Q1's drain load is a portion of coil L2, which ultimately connects to the 9V supply. The junction of L2 and the 47Ω decoupling resistor is bypassed by a 10nF capacitor. As a result, L2 is effectively grounded at this point, as



Scope1 shows the sinewave output of the local oscillator, as measured at TP1. This is low in distortion (low in harmonics) to improve image rejection. It also has low frequency jitter so that noise is not produced in the audio signal after FM demodulation.



SC ©2019 **SUPER-9 STEREO FM RADIO**

Fig.4: each stage in the circuit of the Super-9 Stereo FM Radio is labelled and can be related to the block diagram, Fig.2. Dual-gate Mosfet Q1 forms the heart of the tuned RF amplifier, while Q2 is the mixer and Q3 the local oscillator. IC2 and IC3 form the IF amplifier stages while L6 and associated resistor and capacitor form the quadrature detector for IC3, in conjunction with L5. Varicap diode VC3 provides Automatic Frequency Control for the local oscillator and is controlled from IC3's AFC voltage output.

far as RF signals are concerned.

The full L2 coil is tuned using the 220pF capacitor connected in series with varicap diode VC1. The 220pF capacitor reduces the tuning capacitance adjustment range to 88-108MHz. This capacitor also prevents DC voltage from reaching the anode (A1) from L2. The anode is then grounded via a 68kΩ resistor so that its DC bias is 0V.

We're using a dual varicap diode to minimise signal excursions from modulating the overall total capacitance of the varicap VC1.

So if one of the varicap diodes has signal across it that reduces its capacitance, the opposite varicap diode connected in reverse will have a signal that increases its capacitance. So these effects cancel out.

Tuning is via adjustment of potentiometer VR1. This would normally have an adjustment range of 0-5V, over a travel of 300°.

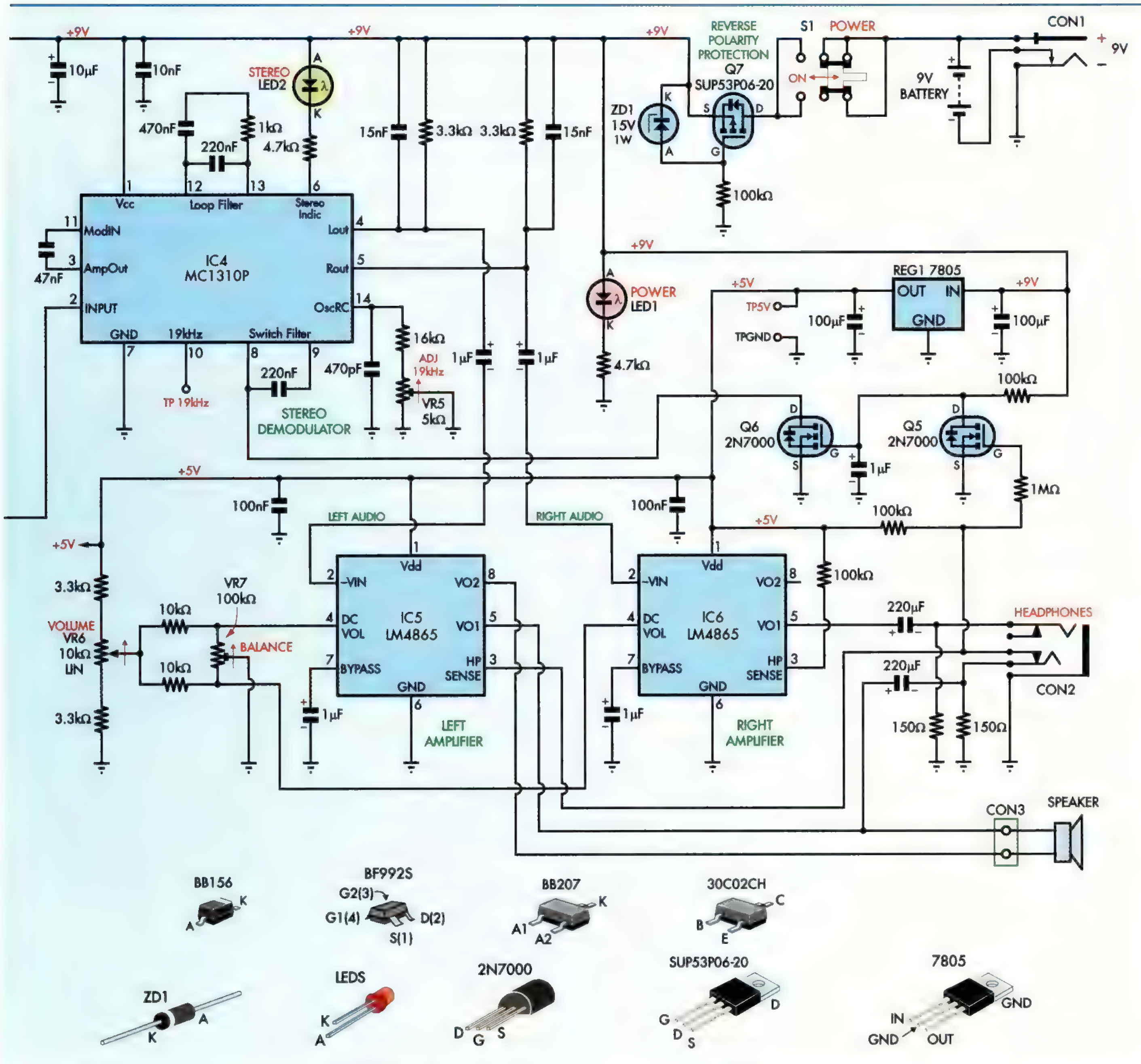
A mechanical stopper is used to restrict the travel range to 180°, so it has a usable voltage range of 1-4V.

Op amp IC1b amplifies this voltage. When calibration trimpot VR2 is set for minimum resistance between pins 6 and 7 of IC1b, IC1b's output range is 1-4V.

With VR2 set for the maximum 10kΩ resistance between these pins, the amplification is 1.5 times (10kΩ ÷ 20kΩ + 1), giving an output range of 1.5-6V. VR2 can be set to an intermediate position for a gain value between 1.0 and 1.5.

VR2 is used to adjust the upper tuning frequency to 108MHz when VR1 is set for the maximum 4V at its wiper. The lower 88MHz tuning frequency (with VR1's wiper at 1V) is adjusted by manipulating the inductance of coil L2, by slightly compressing or expanding it.

The tuning voltage from the pin 7 output of IC1b is reduced by a factor of two using a voltage divider comprising two 4.7kΩ resistors. This voltage



is then filtered by a 10nF capacitor and applied to the common cathode of varicap diode VC1 via a 68kΩ resistor. The resistor is included to provide a high resistance to the capacitor, so that the resonance of the tuned circuit is not loaded.

Local oscillator

NPN transistor Q3 and its associated components make up the local oscillator. Its base is DC biased to about 4.5V by the two 10kΩ resistors connected across the 9V supply and by its 560Ω emitter resistor. The collector load is L4 to its series 47Ω resistor to 9V, with the junction of the two bypassed to ground by a 10nF capacitor.

Q3's base is also connected to a tuned circuit comprising inductor L3 and varicap diode VC2. The other end of L3 is connected to ground via a 10nF AC-coupling capacitor, so that the DC biasing of Q3's base is not affected by L3.

Similarly, a 220pF capacitor between Q3's base and the anode of VC2 isolates the base DC voltage from the varicap diode and reduces the overall capacitance variation for the tuned circuit from the varicap, as for the tuned RF amplifier. A 68kΩ resistor from the anode of VC2 to ground sets its DC bias to 0V. We are using a dual varicap here for the same reasons as described above.

The oscillation frequency is determined by L3's inductance and VC2's capacitance. Oscillation is caused by feedback between L4 and L3. These are mounted adjacent to each other to provide some magnetic coupling between them.

This type of oscillator is known as an "Armstrong" or "Meissner" oscillator, after the original developers of the configuration. It's also sometimes called a tickler oscillator due to the 'tickler' coil L4 exciting the tuned circuit incorporating L3.

Transistor Q4 is a buffer connected in

an emitter follower configuration. This provides a test point at the emitter (TP1) for frequency measurement. Without Q4, an oscilloscope probe or frequency meter connected to the emitter of Q3 would alter the oscillation frequency.

Scope1 shows the sinewave output of the local oscillator, as measured at TP1.

Automatic Frequency Control is provided for the local oscillator using varicap VC3, which is coupled to the L3 tuned circuit via a 2.2pF capacitor.

A single varicap diode is used since the signal level is very low across it, so the signal does not affect its capacitance very much. Its control voltage is derived from the tuning voltage produced by IC3, which will be described later.

The local oscillator is also tuned using VR1. Op amp IC1a provides amplification of the voltage from VR1's wiper, adjusted using VR3. The resulting tuning voltage is applied to the common cathode of varicap diode VC2 via a 68kΩ resistor, similarly as for VC1.

VR3 is used to set the upper local oscillator frequency to 97.3MHz when VR1's wiper is at 4V. The lower 77.3MHz setting (with VR1's wiper at 1V) is made by compressing L3's windings slightly for a lower frequency or expanding it for a higher frequency.

Mixer stage

The output from the local oscillator at Q4's emitter is coupled via a 4.7pF capacitor to one gate (G2) of dual-gate Mosfet Q2. The 4.7pF and 330pF capacitors form a capacitive voltage divider, greatly reducing the local oscillator voltage applied to Q2, so as not to overload the mixer.

Mosfet Q2 functions as the mixer stage. It mixes the local oscillator signal with the tuned RF signal fed via a 220pF capacitor and FB2, to its other gate input (G1). The bias for G2 is set to about 4.77V by two 10kΩ resistors and the 330Ω resistor from Q2's source to ground, while G1 is biased to 0V by a 470kΩ resistor. FB2 prevents parasitic oscillation in Q2.

Q2's drain load is a tuned circuit, peaked at 10.7MHz using a 47pF capacitor and an adjustable ferrite-cored inductor which is the primary of IF transformer T1 (between pins 1 & 2). Since the pin 2 end of the primary is grounded for radio frequencies via a 10nF capacitor, the winding is effectively connected in parallel with the 47pF capacitor.

As a result of this tuning, Q2 operates as a very efficient amplifier over a narrow band centred on 10.7MHz. Frequencies outside the wanted band (including the original RF signal, the local oscillator signal and the sum of these) are rejected. It is only the 10.7MHz difference signal that appears at the secondary of T1.

Further gain

The secondary winding of T1 (pins 3 & 4) couples the signal to the differential inputs (pins 1 & 8) of video amplifier IC2. Its inputs are DC-biased at half supply via a 10kΩ/10kΩ resistive divider across the 9V supply, with a 10nF filter capacitor to reject noise. The 10Ω resistance between pin 2 and 7 of IC2 sets its gain to around 400 times (52dB).

Ceramic filter

The output of amplifier IC2 is fed to ceramic filter XF1 via a 330Ω resistor. This resistor provides the 330Ω source impedance required for the filter to work as designed. The filter output feeds into another 330Ω load resistor, again required for impedance matching.

XF1 provides further rejection of unwanted signals outside the 10.7MHz ±75kHz IF range. It is a bandpass filter with a 10.7MHz centre frequency and a 280kHz bandwidth. The filtered signal then goes to input pin 1 of IC3, the amplifier/limiter/detector. This is a part specially designed for FM radio decoding.

It includes a three-stage IF amplifier and limiter, quadrature detector and an audio amplifier with a squelch feature. Squelch switches the output off if the signal level is so low that the output is just noise.

IC3 also has a signal strength metering output at pin 13 and an automatic frequency control (AFC) output at pin 7. The voltage at pin 7 varies above or below the 5V reference voltage output at pin 10, depending on whether the signal frequency fed into pin 1 is above or below 10.7MHz.

The 5V reference voltage is applied to the anode of VC3 for the local oscillator via a 47kΩ isolation resistor. The AFC output is divided by two using a 47kΩ/47kΩ voltage divider, and this becomes the anode voltage for VC3. So when the tuning is spot on, VC3's anode is at 2.5V. If it starts to drift off station, the AFC voltage will change, causing VC3's capacitance to change, bringing the local oscillator back into tune.

The quadrature components needed for demodulation comprise a fixed 22μH inductor (L5), variable inductor (L6) and the associated 100pF capacitor and 3.9kΩ resistor. See the panel for an explanation on how IC3 and quadrature demodulation work.

L6 is adjusted to resonate at 10.7MHz with the 100pF capacitor. The 3.9kΩ resistor lowers the Q of the tuned circuit to provide a linear voltage variation with frequency, over the frequency range of the FM signal.

Stereo decoding

The audio signal from the demodulator is fed to input pin 2 of the MC1310P stereo demodulator, IC4, via a 2.2μF coupling capacitor. IC4 decodes the left and right channel information included in the transmitted FM signal. It also provides the required 50μs de-emphasis (in both mono and stereo modes), rolling off the audio frequency response above 3.18kHz.

The panel overleaf describes how the stereo signal is recovered.

The de-emphasised audio outputs are from pin 4 for the left channel and pin 5 for the right channel. The 3.3kΩ resistor and 15nF capacitor at each output set the required 50μs time constant (3.3kΩ x 15nF = 49.5μs).

The resulting left and right channel audio signals go to integrated amplifiers IC5 and IC6 respectively. These are used to drive the headphones in stereo mode, via 220μF electrolytic capacitors which remove the DC bias that's present at the amplifier outputs.

When the headphones are not connected, the IC5 drives the loudspeaker in a bridge-tied load (BTL) arrangement. So when pin 8 provides a positive signal swing, the pin 5 output provides a negative signal swing and vice versa.

The result is that the loudspeaker is driven with more voltage and hence the amplifier provides more power (up to four times as much), compared to if only a single output from the amplifier were used.

When driving the loudspeaker, we want IC4 to produce a mono signal so that the speaker reproduces a mix of both the left and right channels (assuming reception is in stereo). But when the headphones are connected, we want the speaker to be switched off and IC4 to provide stereo so that each headphone driver receives a different signal.

Also, the headphones can only be driven in single-ended mode rather than BTL mode, because they share a

common ground connection. This is because typical headphones connectors such as TRS types only have three contacts: one for the left signal, one for the right signal, and a common ground.

The LM4865 amplifier ICs we're using have a clever solution to this. Pin 3 selects whether the output is single-ended or BTL. The switching contact for the tip connection in the headphone socket goes to pin 3 of IC5 but is also tied to +5V via a 100kΩ resistor.

With the headphones not plugged in, the 150Ω resistor pulls pin 3 below 50mV, and this sets IC5 in the BTL mode for driving the speaker.

Pin 3 of IC5 is also applied to the gate of Mosfet Q5. Since this voltage will be low, Q5 is off and so the second Mosfet (Q6) has its gate pulled to 5V by a 100kΩ resistor. With Q6 switched on, it pulls pin 8 of IC4 to ground and this disables stereo decoding. IC5 therefore drives the speaker in mono.

When headphones are plugged in, the switch contact in the headphone socket opens and pin 3 of IC5 is pulled to 5V via the 100kΩ resistor. This changes IC5 to single-ended operation, with output pin 8 floating.

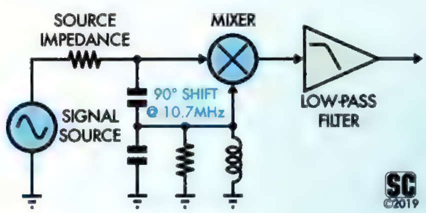
This prevents the speaker from being driven. Only pin 5 is driven, and this powers the left headphone channel. At the same time, the gate of Mosfet Q5 goes high, switching it on and pulling the gate of Q6 low. So Q6 switches off and allows the voltage at pin 8 of IC4 to rise, enabling stereo decoding.

IC6 is always used as a single-ended amplifier, as its pin 3 is held high (5V) via a 100kΩ resistor. That's because this IC is only used to drive the right

How the CA3089 demodulator works

The block diagram of the CA3089 IC, extracted from its data sheet, is shown at bottom. The incoming signal passes through three separate balanced amplification stages, each with its own level detector. The level detector output currents are summed and fed to pin 13, allowing the signal level to be measured. Once the signal enters limiting, that current reaches a maximum value.

The output of the last amplifier is fed to the quadrature detector, which converts the frequency deviation in the signal to a varying output voltage, recovering the audio signal. The way this demodulator works is shown below.



The external RLC network (shown above as two capacitors, an inductor and a resistor) is designed to produce a 90° phase shift at the intermediate frequency; in this case, 10.7MHz. The original and phase-shifted signals are then fed into a mixer, followed by a low-pass filter. This arrangement effectively acts as a phase detector, producing a voltage proportional to the phase difference.

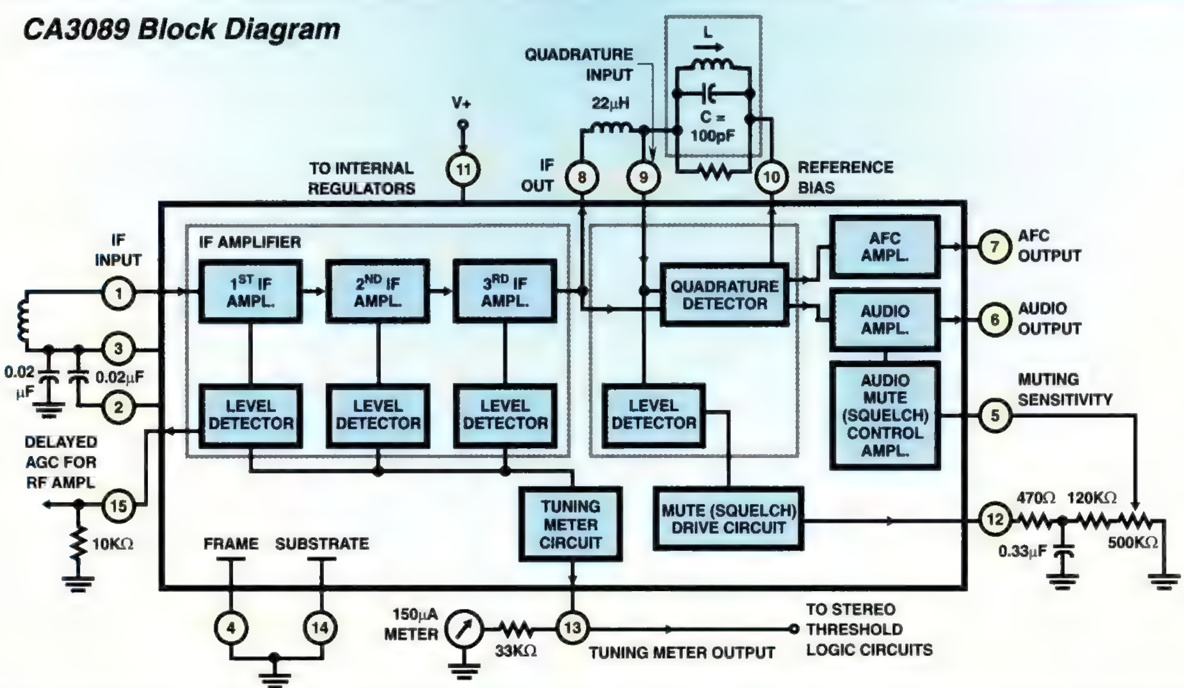
The reason that this works as a demodulator is that the phase shift of the RLC network varies slightly with signal frequency; it will be a bit less than 90° at frequencies below 10.7MHz and a bit more than 90° at frequencies above 10.7MHz. Therefore, the output voltage of the phase detector tracks the frequency deviation of the incoming signal.

The phase shift is not exactly linearly proportional to frequency variation; however, the frequency variation is a small percentage of the carrier (±75kHz compared to 10.7MHz, or about ±0.75%).

The middle section of the frequency/phase curve is substantially linear, so this type of demodulator has very good performance. Distortion levels as low as 0.1% are possible with a well-designed and tuned reactive network. As shown in the spec panel, distortion is often a little lower for less than full deviation, because the demodulator is operating over a more linear part of the curve.

For more details on its operation, see the CA3089 data sheet, which can be downloaded from: siliconchip.com.au/link/aav7

CA3089 Block Diagram



Parts list –Super 9 FM Receiver

1 double-sided PCB coded 06109181, 313 x 142.5mm
2 shield PCBs coded 06109183, 13 x 35.5mm
1 antenna mount extender PCB coded 06109184, 7.6 x 27mm
1 pot travel stopper PCB coded 06109185, 23 x 26mm
1 set of laser-cut acrylic case and dial pieces [Silicon Chip Online Shop Cat SC5166]
1 1.1m telescopic antenna [Silicon Chip Online Shop Cat SC5163, Banggood Cat 1108129]
1 125mm (5-inch) 4Ω loudspeaker [Jaycar AS-3007]
1 Murata SFECF10M7FA00 10.7MHz ceramic filter (XF1) [Digi-key, Mouser, RS components]
1 DPDT push-on/push-off switch (S1) [Altronics S1510]
1 round knob for switch S1 [Altronics H6651]
1 20mm diameter knob for VR6 [Jaycar HK7786]
1 32mm diameter knob for VR1 [Jaycar HK7741]
1 2.1mm or 2.5mm inner diameter PCB-mount DC socket (CON1) [Altronics P0621/P0621A, Jaycar PS0519/PS0520]
1 6.35mm stereo switched jack socket (CON2) [Jaycar PS0190]
1 9V DC 250mA+ plugpack and/or 9V alkaline battery
1 9V PCB battery holder [Altronics S5048, Jaycar PH9235]
1 2-way polarised pin header, 2.54mm spacing (CON3)
1 2-way polarised plug to suit CON3
8 M3 x 15mm machine screws
8 M3 x 10mm machine screws
4 M3 x 15mm Nylon or polycarbonate machine screws
3 No.4 x 6mm self-tapping screws (for battery holder)
4 25mm long M3-tapped spacers
4 15mm long M3-tapped spacers
8 M3 flat washers
24 M3 hex nuts
18 PC stakes
1 300mm length of 0.8mm diameter enamelled copper wire (for L1-L4)
1 1m length of 0.25mm diameter enamelled copper wire (for T1 & L6)
1 80mm length of 0.71mm diameter tinned copper wire
1 40mm length of light-duty figure-8 cable

Coils & ferrites

2 Neosid M99-076-96 K3 transformer assemblies (T1,L6) (M76-403-95 Former K + M76-404-95 Can K + 76-409-95 Ferrite Cup Core S3/K3 + M76-410-95 Screw Core K3/F16) [Silicon Chip Online Shop Cat SC5205; two required]
2 RFI suppression beads, Philips 4330 030 3218 2 (FB1,FB2) [Jaycar LF1250, Altronics L5250A]
1 22µH RF inductor (L5)

Parts for IF alignment oscillator (to be described next month)

1 single-sided PCB, code 06109182, 52 x 30.5mm
1 Murata SFECF10M7FA00 10.7MHz ceramic filter (XF2) [Digi-key, Mouser, RS components]
1 74HC00N high-speed CMOS quad NAND gate, DIP-14 (IC7)
1 1N5819 40V 1A schottky diode (D1)
4 PC stakes

Capacitors

1 100nF MKT polyester capacitor
2 10nF ceramic capacitor
1 330pF ceramic capacitor
1 8.2pF COG/NPO ceramic capacitor

Resistors (all 0.25W 1%)

1 1MΩ 1 330Ω 2 270Ω
1 1kΩ horizontal trimpot (code 102) (VR7)

Semiconductors

1 LMC6482AIN dual CMOS op amp, DIP-8 (IC1) [Jaycar Cat ZL3482]
1 NE592D8R2G video amplifier, SOIC-8 (IC2) [Digi-key, Mouser, RS Components]
1 CA3089E FM IF amplifier and demodulator, DIP-16 (IC3) [Silicon Chip Online Shop Cat SC5164]
1 MC1310P FM stereo decoder, DIP-14 (IC4) [Silicon Chip Online Shop Cat SC4683]
2 LM4865MX/NOPB power amplifiers, SOIC-8 (IC5,IC6) [Digi-key, Mouser, RS Components]
2 BF992 dual gate N-Channel depletion mode Mosfets, SOT-143B (Q1,Q2) [Silicon Chip Online Shop Cat SC5165, Mouser 771-BF992-T/R, RS Components 626-2484]
2 30C02CH-TL-E NPN VHF transistors, SOT-23 (Q3,Q4) [Digi-key, Mouser, RS Components]
1 SUP53P06-20 P-channel Mosfet, TO-220 (Q7) [Jaycar ZT2464]
2 2N7000 N-channel Mosfets, TO-92 (Q5,Q6) [Jaycar ZT2400, Altronics Z1555]
2 BB207 dual varicap diodes, SOT-23 (VC1,VC2) [Digi-key, Mouser, RS Components]
1 BB156 varicap diode, SOD-323 (VC3) [Digi-key, Mouser, RS Components]
1 7805 5V regulator (REG1)
1 15V 1W zener diode (ZD1) [eg, 1N4744]
2 3mm LEDs (LED1,LED2)

Capacitors

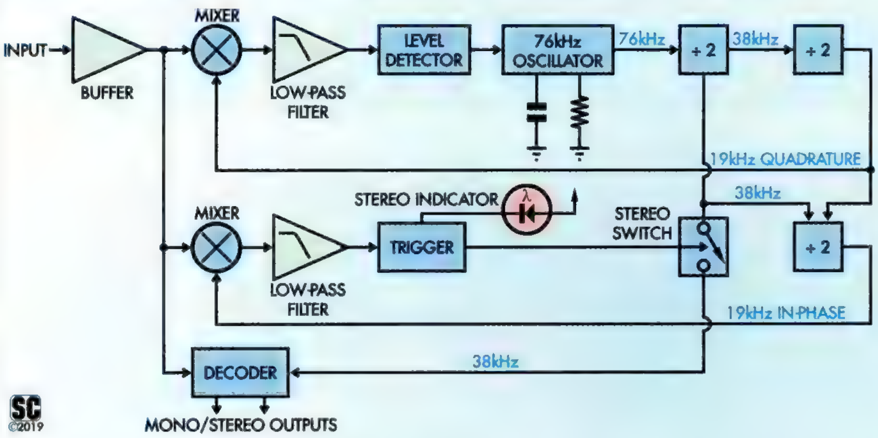
2 220µF 16V PC electrolytic	
2 100µF 16V PC electrolytic	
2 10µF 16V PC electrolytic	
1 2.2µF 16V PC electrolytic	
7 1µF 16V PC electrolytic	*Capacitor Codes:*
1 470nF MKT polyester	*470n, 0.47 or 474*
2 220nF MKT polyester	*220n , 0.22 or 224*
3 100nF MKT polyester	*100n, 0.1, or 104*
1 47nF MKT polyester	*47n, 0.047 or 473*
2 22nF ceramic	*22n, 0.022 or 223*
2 15nF MKT polyester	*15n, 0.015 or 153*
15 10nF ceramic	*10n , 0.01 or 153*
1 470pF ceramic	*470p or 471*
1 330pF ceramic	*330p or 331*
3 220pF ceramic	*220p or 221*
1 100pF COG/NPO ceramic	*100p or 101*
2 47pF COG/NPO ceramic	*47p or 47*
1 39pF COG/NPO ceramic	*39p or 39*
1 4.7pF COG/NPO ceramic	*4.7p or 4p7*
1 2.2pF COG/NPO ceramic	*2.2p or 2p2*

Resistors (all 0.25W, 1%)

1 1MΩ	1 470kΩ	1 120kΩ	4 100kΩ	4 68kΩ	3 47kΩ
1 33kΩ	2 20kΩ	1 16kΩ	13 10kΩ	1 5.1kΩ	4 4.7kΩ
1 3.9kΩ	4 3.3kΩ	3 1kΩ	1 560Ω	1 470Ω	4 330Ω
2 150Ω	3 47Ω	1 10Ω			

2 Alpha 16mm 10kΩ linear taper potentiometers with 6.35mm D-shaft, 23.5mm long (VR1,VR6) [Jaycar RP7610]
1 10kΩ miniature horizontal trimpot (code 103) (VR2)
1 10kΩ multi-turn top adjust trimpot (code 103) (VR3)
1 500kΩ miniature horizontal trimpot (code 504) (VR4)
1 5kΩ miniature horizontal trimpot (code 502) (VR5)
1 100kΩ miniature horizontal trimpot (code 104) (VR7)

How the MC1310P stereo decoder IC works



Shown above is the internal block diagram of the MC1310, based on what is shown and described in the data sheet. The 76kHz oscillator at top middle has its frequency set via an external capacitor and resistor, which is usually connected in series with a trimpot to fine-tune its frequency.

The 76kHz output is divided by two to get 38kHz, then again divided by two by a circuit that incorporates a phase shift, to obtain a 19kHz signal that's 90° out of phase with the 38kHz signal. This is fed to the mixer at upper left, where it's mixed with the incoming signal, then fed to a low-pass filter, then to a level detector to produce a DC voltage proportional to the difference product.

The resulting voltage indicates the phase relationship between the 19kHz pilot tone and the oscillator, allowing the oscillator to be phase-locked with the pilot tone.

A second divider produces a 19kHz signal that's in-phase with the oscillator, which is fed to a second mixer. Its output then goes to a low-pass filter and then a trigger, which is activated when a 19kHz pilot tone is present, and the oscillator phase is locked to it. This then activates the external stereo indicator, along with the stereo switch, which admits the 38kHz signal to the stereo decoder.

When that signal is present, the decoder recovers the L-R signal and then combines it with the L+R signal to recover the left and right channel audio, which is sent to the outputs. In the absence of the 38kHz signal, the decoder feeds the (L+R) mono signal to both outputs.

headphone channel.

IC4 has a stereo LED indicator (LED2) driven by pin 6, showing when IC4 is decoding in stereo. Stereo is available when a stereo jack plug is inserted into CON2, and there is sufficient signal level in the received radio signal for stereo decoding. All Australian FM stations broadcast in stereo.

VR6 is the volume control, which controls the gain of both amplifiers, IC5 and IC6. Padding resistors set its wiper to product a voltage range of 0.8-3.4V.

Balance control potentiometer VR7 alters the voltage applied between the pin 4 volume control inputs of IC5 and IC6, so that when it is rotated off-centre, one amplifier (left or right) delivers more signal.

The maximum volume control signal of 3.4V prevents excessive volume from the headphones and also prevent the loudspeaker from being over-driven.

Power supply

The FM Radio is powered either from a standard 9V battery or 9V DC plugpack. CON1 provides switching so that when the DC power plug is inserted, the 9V battery is disconnected.

Switch S1 interrupts power from both sources, to allow the FM Radio to be switched on and off.

Mosfet Q7 is included for reverse polarity protection. It will not conduct current if the supply polarity is reversed, but unlike a diode, it has a very small voltage drop when it is in conduction.

If the supply polarity is correct, the gate of Q7 will be lower than its source, and so the Mosfet switches on. ZD1 protects the gate from over-voltage. LED1 lights up as a power indicator.

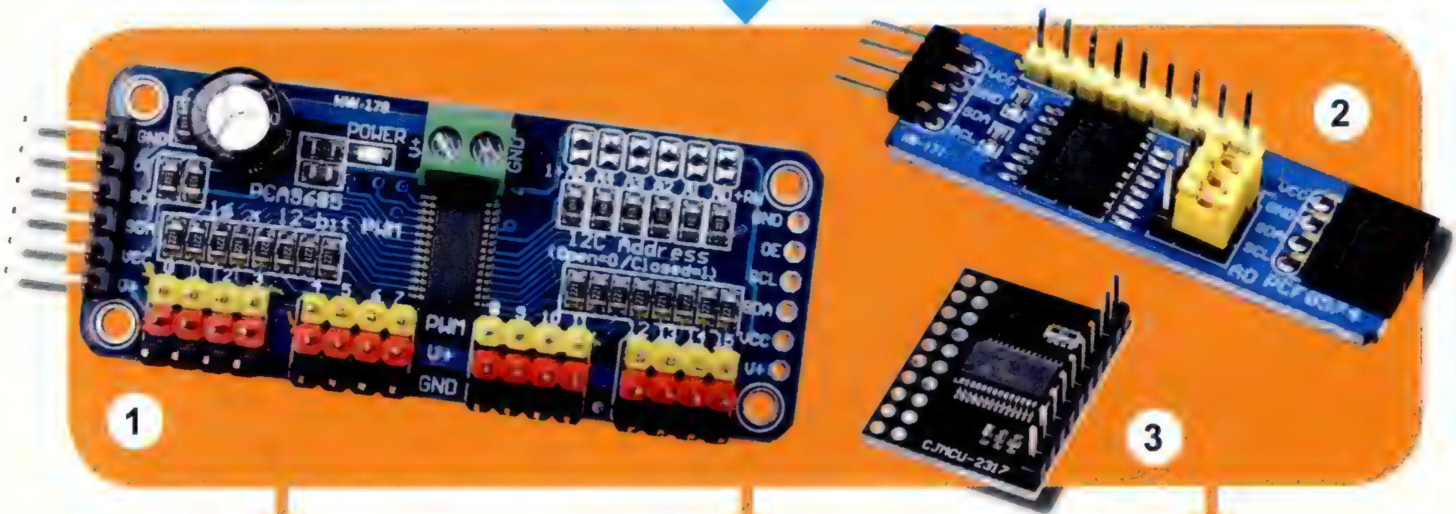
Linear regulator REG1 derives a 5V supply for amplifiers IC5 and IC6 from the incoming 9V, as they require, and also supplies the tuning reference voltage for VR1.

That completes the FM Radio circuit description. Next month, we will complete the project with full details on its construction and alignment and fitting it in its case. SC

Resistor Colour Codes

	Qty	Value	4-Band Code (1%)	5-Band Code (1%)
❑	1	1MΩ	brown black green brown	brown black black yellow brown
❑	1	470kΩ	yellow violet yellow brown	yellow violet black orange brown
❑	1	120kΩ	brown red yellow brown	brown red black orange brown
❑	4	100kΩ	brown black yellow brown	brown black black orange brown
❑	4	68kΩ	blue grey orange brown	blue grey black red brown
❑	3	47kΩ	yellow violet orange brown	yellow violet black red brown
❑	1	33kΩ	orange orange orange brown	orange orange black red brown
❑	2	20kΩ	red black orange brown	red black black red brown
❑	1	16kΩ	brown blue orange brown	brown blue black red brown
❑	13	10kΩ	brown black orange brown	brown black black red brown
❑	1	5.1kΩ	green brown red brown	green brown black brown brown
❑	4	4.7kΩ	yellow violet red brown	yellow violet black brown brown
❑	1	3.9kΩ	orange white red brown	orange white black brown brown
❑	4	3.3kΩ	orange orange red brown	orange orange black brown brown
❑	3	1kΩ	brown black red brown	brown black black brown brown
❑	1	560Ω	green blue brown brown	green blue black black brown
❑	1	470Ω	yellow violet brown brown	yellow violet black black brown
❑	4	330Ω	orange orange brown brown	orange orange black black brown
❑	2	150Ω	brown green brown brown	brown green black black brown
❑	3	47Ω	yellow violet black brown	yellow violet black gold brown
❑	1	10Ω	brown black black brown	brown black black gold brown

I/O Expander Modules



Sometimes, when working with microcontrollers, you just don't have enough pins to do what needs to be done. You might have started with the idea of a simple design but later found out that you had forgotten some crucial features. Uh oh! It can be a lot of work to change to a bigger, more expensive microcontroller, possibly involving learning some new soldering or programming skills. But there's another way out of this pickle.

by Tim Blythman

If you've been working with microcontrollers for long, you've almost certainly run into the situation where you don't have enough I/O pins to do what you need to. Or you've known in advance that you don't have enough pins, but for whatever reason, you don't want to switch to a bigger part. It can be a conundrum.

The ideal solution is to use an I/O expander module. In this article, we describe three different expander modules. They are all controlled over an I²C serial bus, so at worst, they take up two pins on your micro. If you're already using the I²C bus for other purposes, they won't use up any more pins at all.

That's the great thing about I²C; the addressing scheme means that over 100 devices can be controlled by just two lines. Many microcontroller platforms (including Arduino and Micromite BASIC) include native support for I²C.

And all three of the modules we present have the option to change the device address, so multiple expanders can be connected using the same bus. I/O pin counts in the hundreds are easily achievable by using enough of these modules.

The three modules we describe here have a variety of different features, so they have different strengths. We'll describe them according to the IC that they are based around; in each case, the IC data sheet is a great resource to help you fully understand each module's capabilities and quirks.

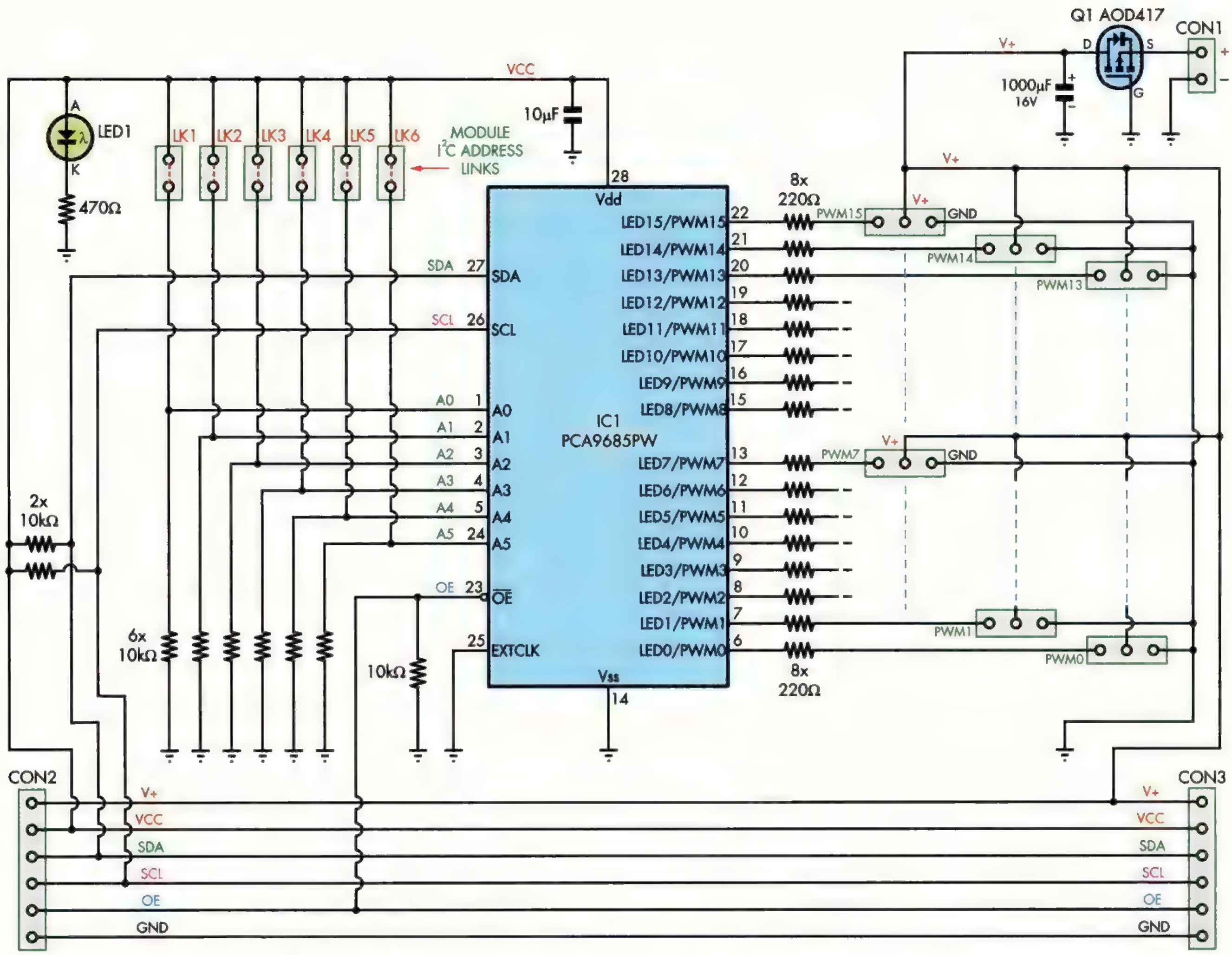
While it's possible to use the bare ICs in your designs, they are all quite small, so by using a module, you not only save the effort of having to solder them, you also get all the other necessary support components along with handy headers to make connecting to other devices a cinch.

Expander 1: PCA9685 module

This module provides up to 16 pulse-width modulated (PWM) or standard digital outputs, which can be used for various purposes including controlling LED brightness or stepper motors.

The PCA9685 module measures 63 x 25mm and features two six-way headers for control, plus 12 three-way I/O headers arranged in groups of four. There's also a two-way screw terminal for power and six pairs of pads which can be bridged to change the IC's I²C address.

The original version of this board was designed by the Adafruit com-



PCA9685-BASED 16 X 12-BIT PWM EXPANSION MODULE

Fig.1: the circuit of the PCA9685 module as designed by Adafruit. Some variants/clones use different resistor values (eg, 120Ω instead of 470Ω, meaning the power LED is very bright) or omit the reverse polarity protection Mosfet or the electrolytic bypass capacitor.

pany, but has been cloned and is also available from several different online stores too. The circuit diagram of the original Adafruit version is shown in Fig.1.

We sourced a few variants of this board, and found that there were a few variations, including one that omitted the reverse polarity protection and one that used different resistor values. Another lacked the bypass capacitor. But they all did pretty much the same job.

The PCA9685 IC

This IC is manufactured by NXP, and the data sheet can be found at: siliconchip.com.au/link/aasl

It runs from 2.3-5.5V, so can work with both 5V Arduinos and 3.3V Micromites, as well as the increasing number of 3.3V Arduinos.

It comes in a 28-pin SSOP or QFN package (both SMD). While it's possible to hand-solder chips this small, we find it easier to use the module if we have enough space to mount it.

While originally intended to be a LED PWM driver, Adafruit sells their PCA9685 board as a servo motor driver. Its 16 PWM channels can operate at up to 1500Hz with 12 bits of resolution (4096 steps), which is more than good enough to generate servo control pulses.

The three-wide rows of pin headers allow many standard servo motors to plug directly into the board. At 50Hz (20ms between the pulses, as in a typical servo signal), pulses can be generated with a resolution of around 5µs, giving just over 200 steps between the standard servo pulse width limits of 1ms and 2ms.

With these normally corresponding to positions of 0° and 180°, this gives a mechanical resolution of slightly better than 1°.

One interesting feature which may come in useful is that the PWM outputs can be started at different times, giving them different phases throughout the PWM cycle, although all outputs must run at the same frequency.

So for example, if you are driving multiple LEDs at less than full duty, they can be timed to stagger their switch-on times, such that (for example) only one is switched on at a time. This will limit the current steps drawn from the supply and probably reduce EMI too.

With the addition of a high-current buffer (eg, a Darlington array), this board could even be used to drive a stepper motor or brushless DC motor.

By staggering the phases and changing the frequency, the output of the PCA9685 can be set to produce a pulse train sufficient to allow the motor to keep turning without further intervention.

We tested out some possible approaches to generate motor drive signals with this module, and some examples of the waveforms we came up with are shown in oscilloscope grab Scope 1.

Module description

Apart from the 16 sets of output pins (each output is paired with a dedicated GND and power pin), there are also headers for power and I^{2}C bus connections as well as six solder jumpers to allow the address to be set.

An output enable (OE) pin is also broken out on the board, allowing all outputs to be enabled or disabled with a single signal, but an external clock connection is not provided. The module relies on the chip's internal 25MHz oscillator instead. The external clock pin is grounded as per the data sheet's recommendation for when it is not used.

Referring to the circuit diagram in Fig.1, we see that there are two different supply rails on the board. A nominal 5V rail powers the chip and can be found on the six-way headers at the pin marked V_{CC}. In a 3.3V system, this would be connected to the 3.3V rail.

A second rail marked V_+ is also available at the six-way header as well as the two-way screw terminal. A diode-wired Mosfet provides reverse polarity protection if power is fed into V_+ from the screw terminal but not from the header. A 1000µF capacitor bypasses the V_+ rail.

There is no connection between V_+ and V_{CC}. The intention is that servo motors (if connected) run from the V_+ rail, while the logic runs from V_{CC}, minimising interaction between the logic and power parts of the circuit. All they have in common is a ground connection.

A separate bypass capacitor for the IC and the power indicator LED is also fed from V_{CC}. Apart from the external clock pin, all the IC's pins are broken out.

The six address pins (A0-A5) are normally pulled to ground by 10kΩ resistors, but they can be individually pulled high if the associated solder jumper is bridged.

While this might appear to give up to 64 available addresses, due to I^{2}C reserved addresses and auxiliary addresses for the PCA9685, the actual usable number is 55, using the (7-bit) range 64-119, excepting 112.

By default, with no jumpers set, the board has a 7-bit address of 64 or hexadecimal 0x40. The six jumpers effectively set the value of the six low order address bits.

Address 112 is designated as "All Call" and can be used to address any PCA9685 device regardless of its set address. This allows initialisation of a large number of ICs to occur quickly, by setting all attached devices to the same initial conditions.

During initialisation (or at any other time), the outputs can be set to open-drain (pull low or high-impedance), push-pull or inverted push-pull configurations.

The 16 PWM outputs are brought out to the top (yellow) row of pins on the board, where they are combined with a row of V_+ (red) and GND (black) headers to form a row of servo motor compatible connection points.

The OE (output enable) pin is brought out to the six-way headers but is also pulled to GND by a 10kΩ resistor, so the outputs are enabled by default. This line can be pulled up by a host micro to shut down the outputs if necessary.

The I^{2}C SDA and SCL pins are also brought out to the six-way headers and these have 10kΩ pull-up resistors. While this is higher than the recommended 4.7kΩ value for I^{2}C bus lines, we had no trouble without adding external pull-ups. Later, we will look at how these resistors behave when multiple boards are connected.

Cleverly, the two six-way headers have matching pin-outs, so boards can be stacked end to end, for example, by fitting a female header to one end and a male

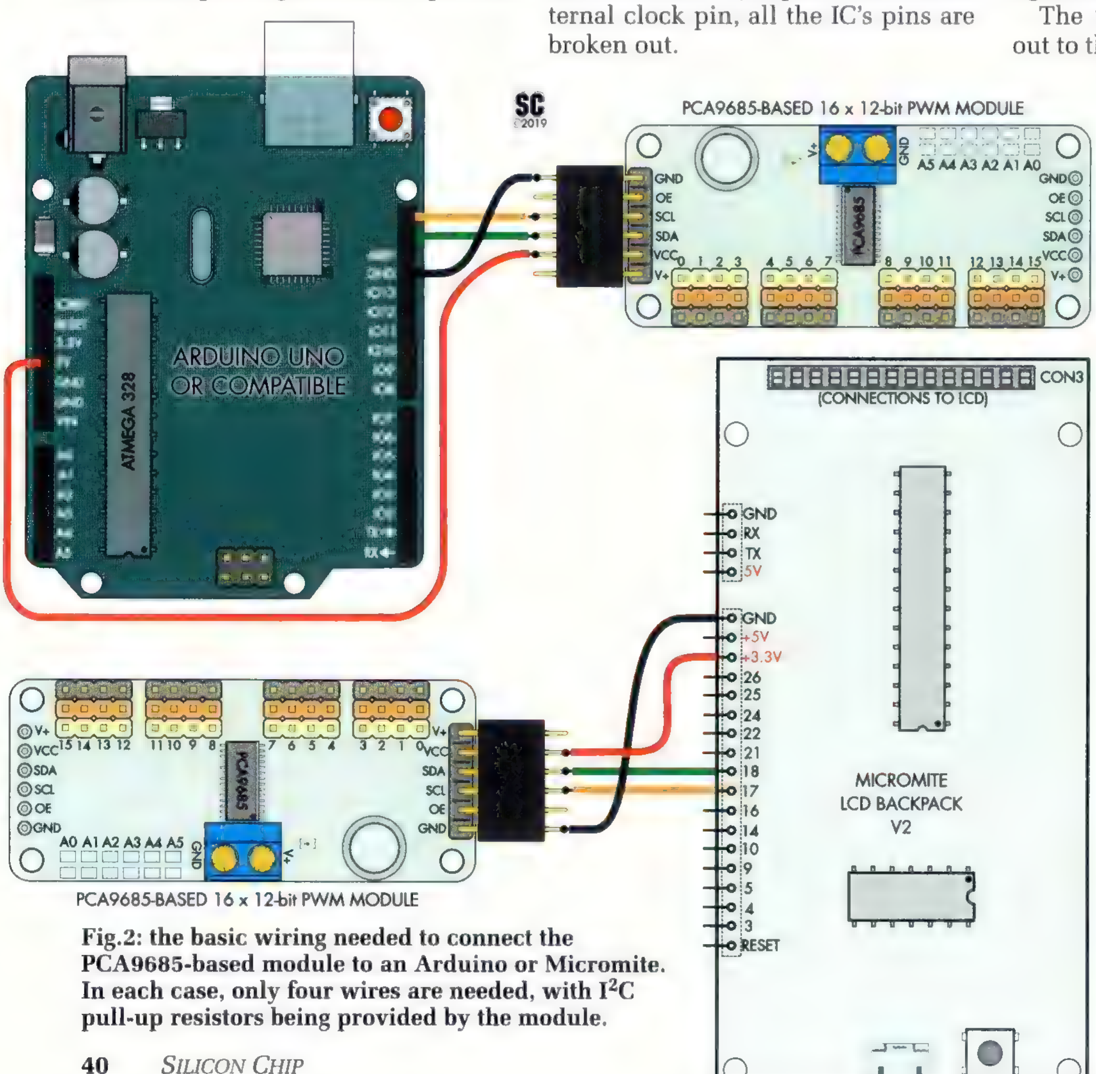
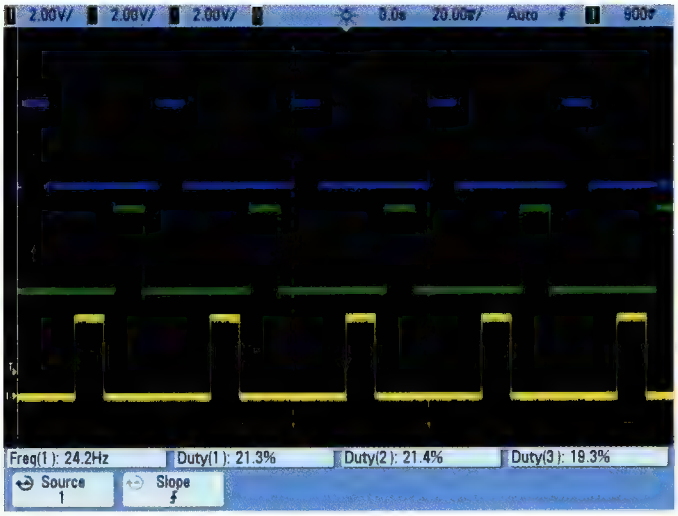
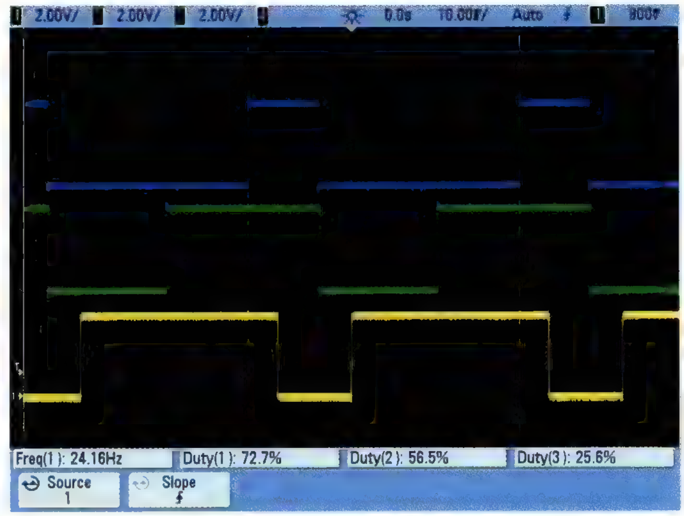


Fig.2: the basic wiring needed to connect the PCA9685-based module to an Arduino or Micromite. In each case, only four wires are needed, with I^{2}C pull-up resistors being provided by the module.



Scope 1: here we're using the PCA9685 module to generate pulse trains each phase shifted by approximately 120° compared to the last. Waveform like this could be used to drive a brushless motor or spread out the current demand of multiple PWM loads.



Scope 2: this demonstrates using the PCA9685 module to produce three different PWM waveforms with different rise and fall positions, with each duty cycle being fully adjustable. The main restriction is that the repetition frequency of all outputs must be the same.

jumper to the other. The V_+ track is quite thick, and the GND trace consists of a solid copper pour on the back of the PCB, so passing a fair amount of current between boards is possible.

It appears the board is quite well designed and breaks out practically all the useful features of the PCA9685 IC.

What needs to be connected?

For basic testing, only four wires are needed: V_{CC}, GND, SDA and SCL. If you wish to connect a servo motor to the headers, you will need a supply for the V_+ rail too. The basic connections for a Micromite and Arduino are shown in Fig.2.

Software

We have written sample programs for Arduino and Micromite. Both of these allow the PWM frequency to be set, as well as the start and duration times of the pulses.

Internally, the PCA9685 uses start and end variables to define the pulse parameters of each output, as well as specific bits to enable full-on and full-off states, so some minor translation is done by the code.

In the Micromite example, these variables are set by sliders on an attached ILI9341 LCD (as you would have on a Micromite LCD BackPack), while the Arduino code uses the serial monitor as a menu to enter the parameters, these being a letter for the parameter followed by its value.

Both examples contain some functions to simplify writing your own code to control the module. Adafruit has also written an Arduino library which can be found at https://github.com/adafruit/Adafruit-PWM-Servo-Driver-Library

Our sample code is available as a free download from the Silicon Chip website.

Expander 2: PCF8574 module

You may have heard of the PCF8574 before, especially if you have ever used any of the I^2C-controlled character LCD panels, as described in our March 2017 article (siliconchip.com.au/Article/10584). It is the PCF8574 that provides the I^2C-to-parallel conversion that makes it so easy to use these LCD screens.

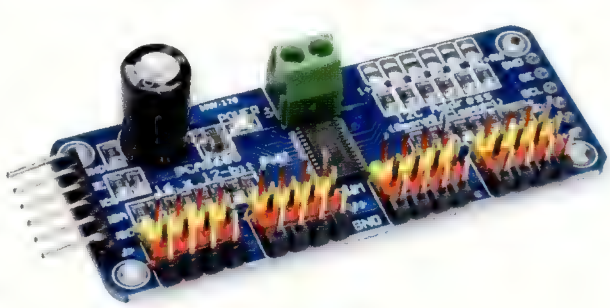
The module we are looking at, designated HW-171, measures 48 x 11mm, although other similar modules are available. Its circuit diagram is shown in Fig.3. It has a wide operating voltage range, 2.5-6V, making it suitable for all 3.3V and 5V applications.

The I^2C modules designed to attach to the back of an LCD panel can also be used as I/O expanders, although they usually omit one of the pins as only seven control lines are needed for driving a character LCD.

This module has a simple interface, with a four-pin male header at one end and a four-pin female header at the other end for control and daisy chaining. The pins are designated V_{CC}, GND, SDA and SCL, with the last two being the I^2C bus. A nine-way header breaks out the I/O ports on one side (the ninth pin provides an interrupt function), while a row of three three-pin headers with jumper shunts are used for address selection.

The male/female pin header combination allows multiple modules to be easily connected to the same I^2C bus, and the addressing scheme allows up to eight unique addresses.

Apart from the main IC, the only other electronic components on the module are a pair of 1kΩ pull-up resistors on the I^2C lines. These are much lower values than are typically used as I^2C pull-ups, but it still seems to work OK. We'll have a look at the effects of these resistors a bit later.



The PCA9685-based module is one of the better designed I/O expander modules. Practically all the available pins are broken out, with the control pins replicated at each end, to allow multiple modules to be daisy-chained.

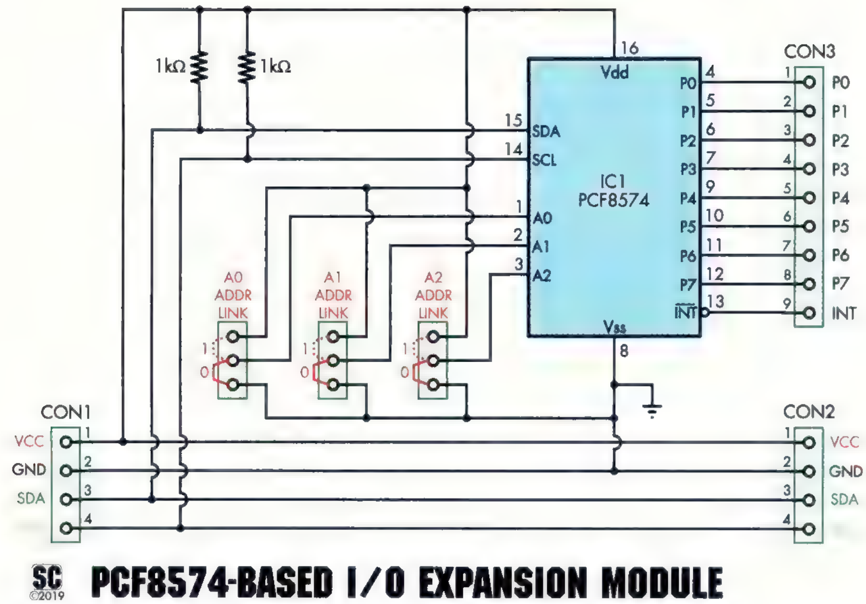


Fig.3: the circuit of the PCF8574-based module. Apart from the main IC, there are just two extra resistors. It's a great module in that all the useful pins are broken out in a well laid out arrangement.

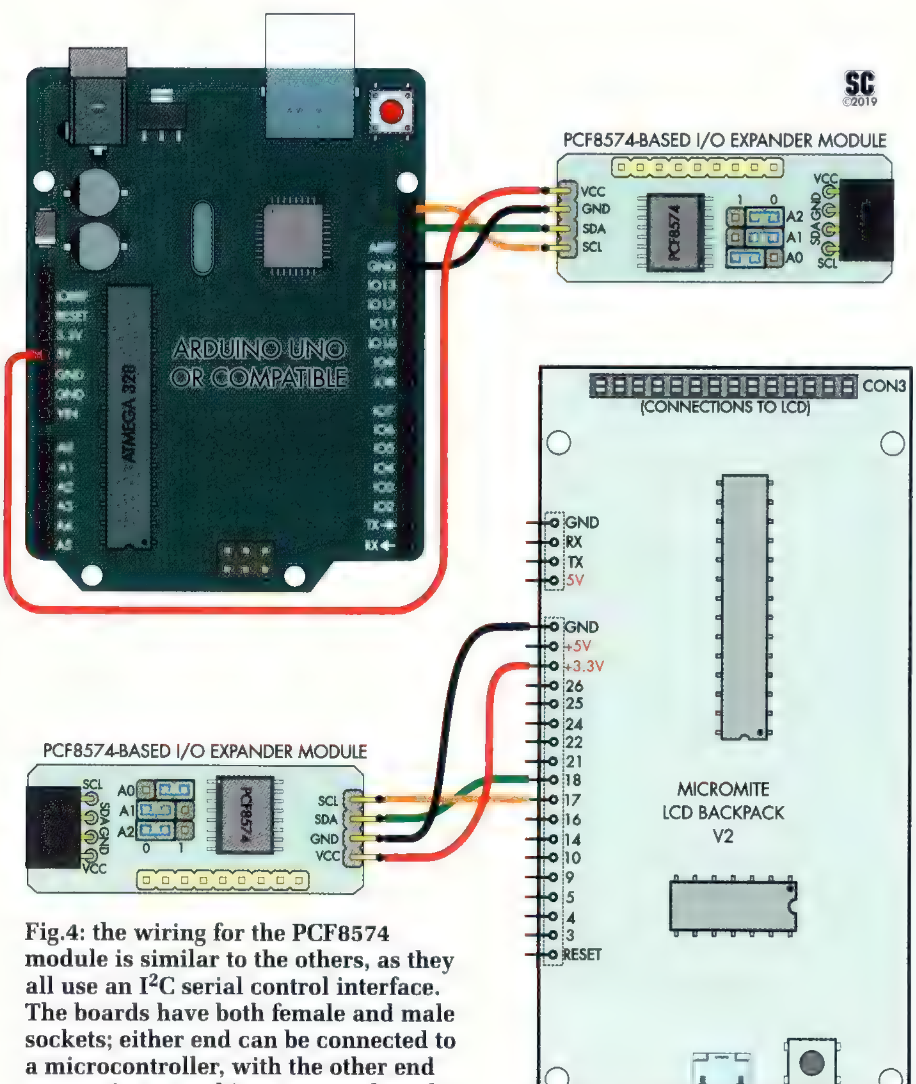


Fig.4: the wiring for the PCF8574 module is similar to the others, as they all use an I²C serial control interface. The boards have both female and male sockets; either end can be connected to a microcontroller, with the other end connecting to nothing, or more boards.

The PCF8574 IC

Like the PCA9685, the PCF8574 is made by NXP. Its datasheet can be found at: siliconchip.com.au/link/aasm

While it can only have eight different addresses, there is a variant called the PCF8574A, which is identical but has a different set of addresses, giving 16 total possibilities.

The PCF8574 can have a 7-bit address from the range 32 to 39, while the PCF8574A can have an address from 56 to 63. Our units had a default address of 32. Since the chips are interchangeable, if you can't get your module to work, check which of these two chips it has.

While NXP does not make a DIP version of this IC, Texas Instruments does, so it is possible to replicate the functions of this module on a breadboard with the addition of two pull-up resistors for the I²C bus.

The datasheet mentions the PCF8574's suitability for driving LEDs, but unlike the PCA9685, this device is quite minimalist and so can only switch them on or off. But it does provide the ability to read the state of each pin, allowing them to be used as digital inputs, which the more complex PCA9685 does not.

Each of the eight I/O pins can be set to one of two states. The default power-up state is for the pins to be pulled up by a 100µA current source. In this state, the pin can be used as an input, detecting when a connected device pulls the pin low. The 100µA current source is also sufficient to drive a logic pin high, such as when the PCF8574 is used to drive alphanumeric LCD screens.

The other state is to pull the pin low. Each pin can sink up to 10mA. A brief 1mA pull-up current is applied on a transition from low to high, supplementing the weak 100µA pull-up and speeding up transitions.

While this scheme appears very basic, it allows all the pins to be written and/or read with a single byte command. Since repeated reads or writes can occur during the same I²C transaction, complex wave trains can be generated as easily as port writes on a microcontroller.

This is perfect for controlling devices such as the character LCDs we mentioned earlier, as a stream of digital data is often needed to update a series of characters on the display.

The PCF8574 modules are designed to be stacked end-on-end, meaning that it's trivial to connect multiple such modules to a single microcontroller. Note that the address jumpers are set here to give each module a different I²C bus address, to avoid conflicts.

The interrupt pin is an open-drain active low output, and goes low on any change of input pin level. It is reset when a read occurs. It is intended to signal to the microcontroller that the input state(s) have changed and require reading. The interrupt pins of multiple modules can be paralleled, as any device can assert a low without conflicting with other modules.

With such a simple control scheme, no initialisation or command codes are needed; the data that is written or read corresponds precisely to the pin states.

Module description

The module itself is quite simple, as noted above, with only two resistors in addition to the main IC.

While the stackable feature of the modules is handy, it's a pity that the interrupt function is not brought out to a fifth pin at each end, to make it easy to feed this signal back to the controller.

V_{CC} and GND pins near the I/O pins would have been nice too; as it is, there is nowhere convenient to connect the controlled device to the power supply.

As for the other module, only four connections are needed: V_{CC}, GND, SDA and SCL. See Fig.4 for the recommended connections to either a Micromite or an Arduino.

Software

As for the PCA9685 module, we have created both an Arduino and Micromite example program. The Micromite program uses a touch panel interface, while the Arduino program uses a serial interface.

Entering any of the numbers 0-7 will toggle the state of that output pin. The pin states are also read and the current state displayed. A read can also be performed by pressing the "READ" button or entering "R" on the Arduino software.

To help with troubleshooting, we've found some small I²C scanner programs (for Arduino and Micromite) and included them in our software download for this article.

These scan all addresses on the I²C bus and determine which addresses are actually in use. That might help you figure out which address your module is set for, if you can't figure it out from the jumpers and IC code.

Expander 3: MCP23017/S17 module

The MCP23017 IC is produced by Microchip, the same company responsible for PIC microcontrollers. It has 16 bi-directional digital I/O ports and is controlled over an I²C bus. There is an SPI version, which is called the MCP23S17. The module suits either version of the IC, as some of the pins are marked with designators for both I²C and SPI signals.

The MCP23017 IC has a working range of 1.8-5.5V, so this module is suitable for use with both Micromites and Arduinos. It is quite compact, measuring just 25 x 20mm, although this means that it only has space to label the functions on the back of the module. It has 30 pins in total, although they do not come fitted with headers.

It supports full bi-directional I/O operation on all pins. The register set is reminiscent of a PIC microcontroller, with control bytes for direction, pull-ups, output latches, port reading and interrupt enable. There's also another byte which can be used to invert the polarity of the port.

Given this many registers, there's a greater level of control than for the PCF8574-based module, including full push-pull output drivers, although it lacks the PWM feature of the PCA9685.

Just like a PIC microcontroller, all the I/O pins start as inputs but can be set to be outputs. The commands are simple, and consist of the IC address (as for all I²C transactions) followed by a command (register) byte and data byte. Port writes up to eight bits wide are possible. Its data sheet can be found at: siliconchip.com.au/link/aasn

Module description

There are two rows of ten pins at one end of the module with the connections to the controlled I/O ports (16 pins) plus connections for interrupt signals and power. There is another single row of 10 pins with the connection to the host for control and power; other non-I/O pins such as the address pins are broken out here too.

But the small size of the module means that some of the nicer features found on the other boards are omitted. For example, although the MCP23017 has three address pins to allow addressing up to eight modules, these pins aren't broken out to jumpers. To use them, you have to solder a wire from one or more of the address pins to the ground pin.

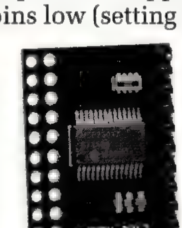
Similarly, there isn't a header to allow multiple modules to be easily stacked. So it's most easily used when it's the only expander module connected to the micro.

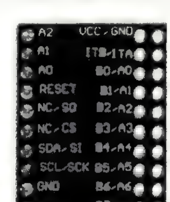
The fact that the two rows of output pins are adjacent means that the module does not lend itself well to being used on a breadboard, unless you're happy using just one row of the output pins.

The circuit

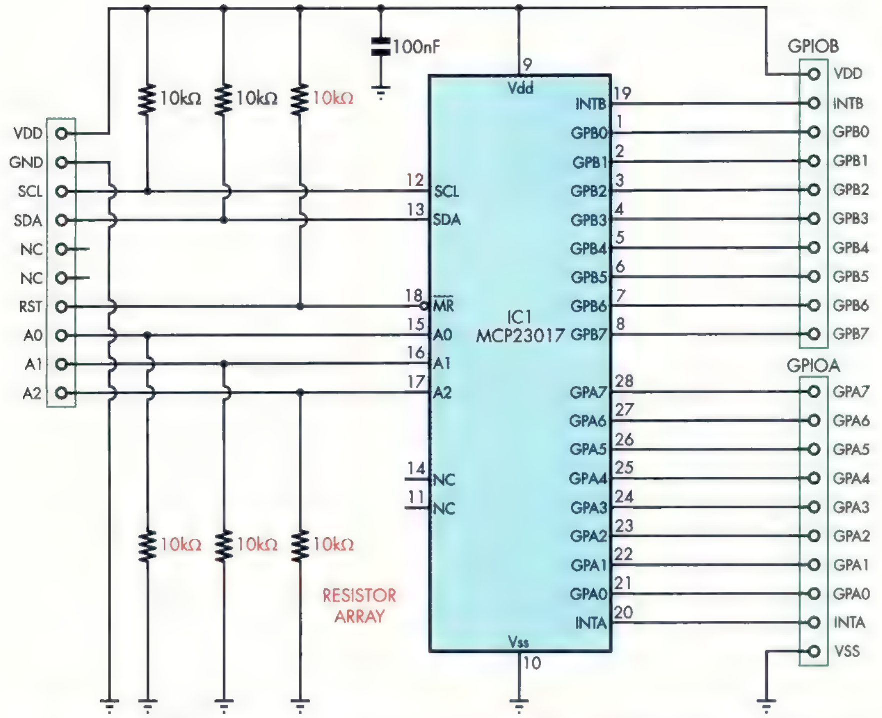
The circuit diagram for this module is shown in Fig.5. Apart from the main IC, there are two 10kΩ resistors, one four-way 10kΩ resistor array and a 100nF ceramic capacitor, used to bypass the IC's supply.

The two individual resistors are the I²C pull-ups, while the resistor array is connected to pull the RESET ($\overline{MR}$) pin high (so the chip will operate as soon as power is supplied) and the address pins low (setting the default address).





The MCP23017 module does not feature stackable headers or address jumpers, but it is very compact and provides full digital I/O control of 16 pins, similar to that of a microcontroller. Due to its small size, the pins are labelled on the back of the module.



SC ©2019 **CJMCU-2317 (MCP23017) I/O EXPANDER MODULE**

Fig.5: the MCP23017-based module is quite compact, although this does leave it at a minor disadvantage for usability compared to the other two modules. The I²C and power pins are on one side, with the I/O pins on the other side.

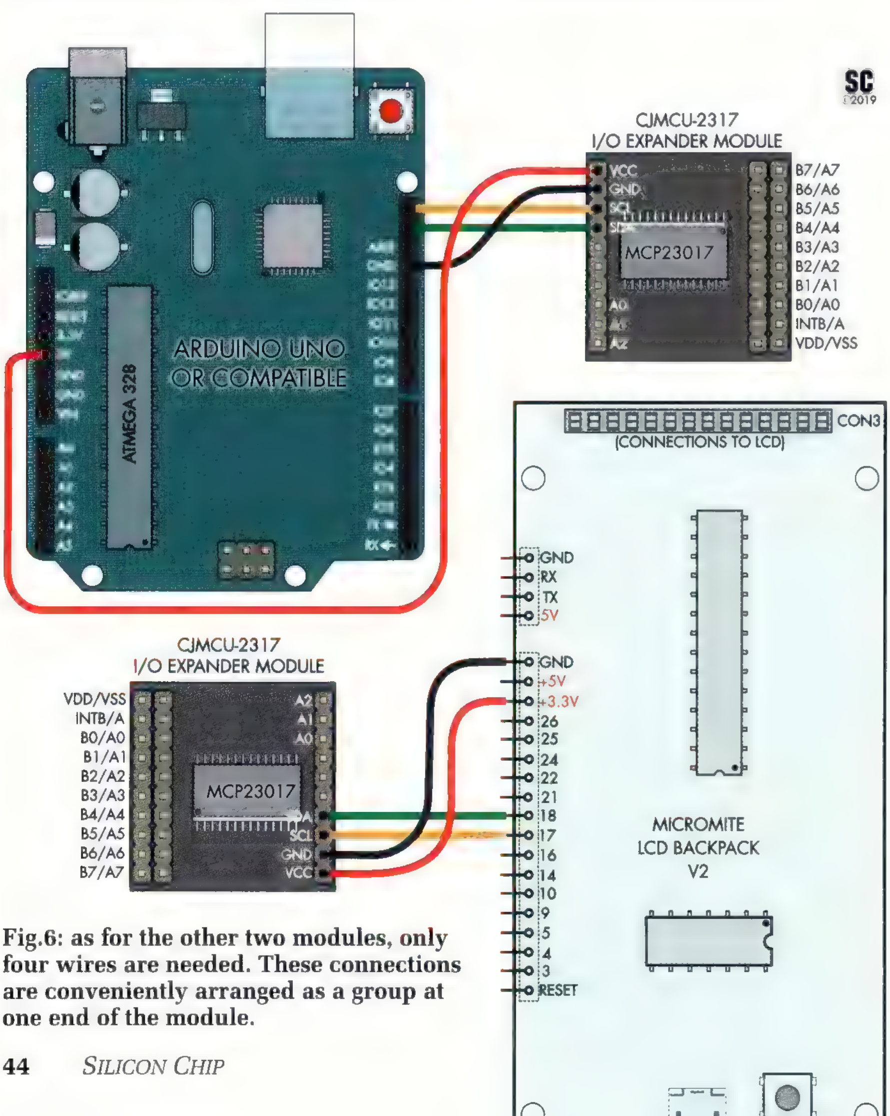


Fig.6: as for the other two modules, only four wires are needed. These connections are conveniently arranged as a group at one end of the module.

Otherwise, all the IC's pins are connected directly to pads on the module, with power (V_{CC}) and ground being the only pins connected via both sets.

For basic operation, only four wires need to be connected; power, ground and the two I²C lines. These connections are sufficient to work with our sample code, and are shown in Fig.6.

Software

Because the MCP23017 works similarly to microcontroller I/Os, we have written our code to emulate the most common microcontroller pin control functions.

For Arduino, the functions are named:

```
MCP23017digitalWrite()
MCP23017digitalRead()
MCP23017pinMode()
```

These work the same as their native counterparts. Our sample code is nothing more than the classic 'blink' routine (which toggles an output between high and low at 1Hz), with code added to read back the set state.

The Micromite code is similar, although the syntax of the commands is slightly different from the inbuilt statements. The functions are named:

```
MCP23017SETPIN
MCP23017READPIN
MCP23017WRITEPIN
```

The pin modes are:

```
OUT
IN
IN_PULLUP
```

The Micromite code draws buttons on an attached ILI9341 LCD screen in landscape mode. Four rows of sixteen buttons correspond to the 16 I/O channels and four states; the states are: input, input with pull-up, output high and output low. A further row shows the last states read from the I/O pins. Pressing any of the buttons, including the "read" button, will cause the read states to be updated.

I²C pull-ups

All three of these modules communicate via I²C, and all have onboard pull-up resistors. The total pull-up resistance decreases as more boards are added and the resistors are effectively paralleled. We investigated what range of resistances allowed for correct operation, to get an idea of how many boards could realistically be used without modification.

For the Micromite, 220Ω pull-up resistances for SDA and SCL result in

15mA being sunk from the 3.3V supply when the pins are driven low. This is the absolute maximum pin current of the PIC32, and even under these conditions, I²C communications at 400kHz (the Micromite's upper speed limit) worked flawlessly.

So a maximum of four PCF8574-based modules or 45 PCA9685-based modules can be connected to a Micromite, based on current draw on the I²C pins. This does not take into account extra capacitance which may be added to the bus lines when extra modules are added, so these numbers may not be achievable in practice.

Removing the resistors from some of the modules will decrease this load, as will adding a second I²C bus.

Similarly, the ATmega328 processor on an Arduino Uno supports a maximum of 40mA on each pin, which corresponds to 125Ω pull-ups to the 5V supply. So we tested using 150Ω pull-up resistors.

This too proved to work fine for both modules, suggesting up to six PCF8574-based modules or 66 PCA9685-based modules can be connected to an Arduino board. This includes the same assumptions as earlier, and these results may not be achievable in practice.

It appears that the I²C bus is quite robust, and can work well if it's operating slightly outside its recommended conditions.

Although we didn't run any tests on the MCP23017 based module, based on these results, it should work fine with up to eight modules (the maximum that would be addressable).

Level shifting

Another interesting possibility that arises in using I/O expander modules is that it allows for parts of the circuit to operate at different voltages.

As I²C is an open-collector bus, devices either pull the SCL and SDA lines to ground or let them rise to a higher voltage due to the pull-up resistors. So it isn't necessary for all devices on the bus to have an identical logic high voltage.

If the bus pull-ups are connected to the lowest voltage supply used, no damage can occur through over-voltage. As long as this level is detected as high by the device with the highest logic voltage, then it will still work, although with reduced margin in clearly defined logic levels.

It's important in this sort of situation to ensure that the pull-up resistors that are connected to the bus go only to the lower voltage supplies (although most chips have internal clamp diodes which will clamp the high voltage to a safe level anyway).

So for example, you could connect an I/O expander module running off 5V to a 3.3V Micromite and it should work just fine.

You would then have 3.3V I/Os available direct from the Micromite, and 5V I/Os from the expander. Ideally, the I²C pull-ups should go to the 3.3V supply.

Similarly, you could connect a 3.3V I/O expander to a 5V Arduino micro. In this case, you would want to use the pull-ups on the expander module. The Arduino will read 3.3V as a high level, and while it will have its own 5V I/Os, you can also use the 3.3V I/Os of the expander module to communicate with other devices running at 3.3V.

One of these expander modules may even be the easiest and cheapest way to communicate with a chip that has a digital interface operating at a different level to your micro.

Note though that the resulting I/O speeds will not be very high; this is another factor to be considered.

Summary

Each module described here provides quite a different set of features, so which one is best for you will depend on your needs. You may even find it handy to connect multiple different expander modules to a single micro to perform different jobs.

For PWM or servo control, or LED brightness control, the PCA9685 module is the most useful. Its large number of possible addresses is also a strength. But it doesn't provide you with any extra digital inputs.

The PCF8574 module is the simplest and easiest to use.

If you need more full-fledged microcontroller type I/O pins, then the MCP23017 module has the advantage. There is extra overhead in controlling it compared to the PCF8574, but this is offset by extra features and more I/O pins.

As mentioned above, you can mix and match the modules, although it is an unlucky coincidence that the MCP23017 and the PCF8574 both share the same address space. SC

Tiny LED Christmas Tree

Here's a brilliant little – and cheap – project for Christmas. It's a mini Christmas tree with 12 multi-colour LEDs which flash in sequence. It runs off a button cell which can last for weeks or even months. You can use whatever colour LEDs you want, or even mix them. You could build several of these, or even dozens, and arrange them around your tree (or anywhere else) for a spectacular light show!

by Tim Blythman

Our **huge Stackable LED Christmas Tree** from last year was a big hit, at least in part because you could use it to build a vast tree, up to a metre high – or even taller.

This project is at the other end of the spectrum; you can build trees so tiny that you could wear them as a badge, attach them to Christmas presents . . . or even use them to decorate a larger Christmas tree. You could even hang them on the giant LED tree (you could call it "Tree-ception").

PCBs and kits for last year's expandable tree (November 2019; siliconchip.com.au/Article/11297) are still available. So if you want a big, illuminated tree, go for it. But if you want to try something a little different, read on.

This idea came about when my wife said she wanted to create some decorative baubles for the festive season. They had to be small to be practical, and as I was involved in the design, naturally they would need flashing lights.

Thus was born the idea of the Tiny LED Christmas Tree.

The electronics are not extraordinary, except perhaps in their simplicity. An 8-pin microcontroller running from a single lithium cell drives 12 LEDs.

It's using a multiplexing method that we've used before, known as 'Charlieplexing', to allow the twelve LEDs to be driven from just four I/O pins. See the side panel for more information on this.

We've used a PIC12F675 as the microcontroller primarily because it has a low sleep current and comes in a modestly-sized 8-pin SOIC package, with enough spare I/Os to drive the 12 LEDs.

As the board is shaped like a tree, the obvious choice of

Front and back of the PCB, shown here life size. The LEDs are mounted on the front with their cathodes to the left, (indicated by a small green mark on the LEDs we used). We used a mix of LEDs on our tree; the different colours are hard to tell apart once they have been removed from their package, although white LEDs can sometimes be discerned by their yellow phosphor. On the back of the PCB are the rest of the components: the PIC IC, five resistors and the button cell battery. The orientation of the IC and the cell holder is important. While not visible from directly above, the holder has tabs on its left-hand side that prevent a cell passing out this side. If the holder is installed backwards, one resistor gets in the way of inserting the coin cell.

solder mask colour is the default green, and you can use whatever colour LEDs you want on top of that: red, green, yellow, orange, blue, white or a mixture.

But as ornaments are best when they're bright and cheerful, we're also offering boards with red and white solder masks, along with the green mask shown here.

You could build a mix and use different colour LEDs with each board colour.

Circuit details

Fig.1 shows the full circuit (not much to it, is there!). Two of microcontroller IC1's eight pins are dedicated to its power supply, and these are connected directly to the terminals of a button cell.

We've found that in this application, no bypass capacitor is necessary. These power pins and three other pins required to program the chip in-circuit are also connected to programming header CON1.

This header is mounted on a part of the PCB that's separated from the rest by a row of holes, allowing it to be snapped off if it isn't needed (eg, if you purchased a pre-programmed PIC, or you've already programmed the chip).

Pins 6, 2, 5 and 3 are used to drive the LEDs via 1kΩ current-limiting resistors, leaving pin 4 (GP3/$\overline{\text{MCLR}}$) and pin 7 (GP0/PGED), both of which can be used as I/Os but in this case, are only used for programming the chip.

Part of the reason we aren't using pin 4 to drive the LEDs is that during programming, a high voltage is applied to this pin, which could damage the LEDs.

In its role as $\overline{\text{MCLR}}$, pin 4 needs a pull-up for normal operation (to avoid 'random' resets). So we've connected a 10kΩ resistor between $\overline{\text{MCLR}}$ and Vdd.

Pin 7 is also not used for the LEDs as this might interfere with the programming of the chip. Pin 6 (GP1/PGEC) is used for both programming and driving the LEDs. We've gotten away with this as it is the only programming pin that connects to the LED array.

The circuit is designed to drive one LED at a time. While it is possible to give the illusion of multiple LEDs being illuminated by multiplexing them fast enough, we've found that we can get a nice display by flashing the LEDs in sequence, and therefore that is not necessary.

With this configuration, the current for each LED passes through two of these resistors. That's because, to drive an LED, one of the four connected I/O pins is driven high and another of the four low. The two remaining I/Os are left in a high-impedance 'floating' state.

This forward-biases one of the twelve LEDs. The other eleven are either reverse-biased, or they have a floating anode or cathode, so no current can flow.

Table 1 shows which combination of pins is used to light each LED in turn.

To simplify the layout of the PCB, the LEDs are not arranged in numerical order. The mapping of logical to physical location is handled in the software programmed into the PIC. The physical layout can be seen in the top side PCB overlay diagram, Fig.2(a).

By the way,

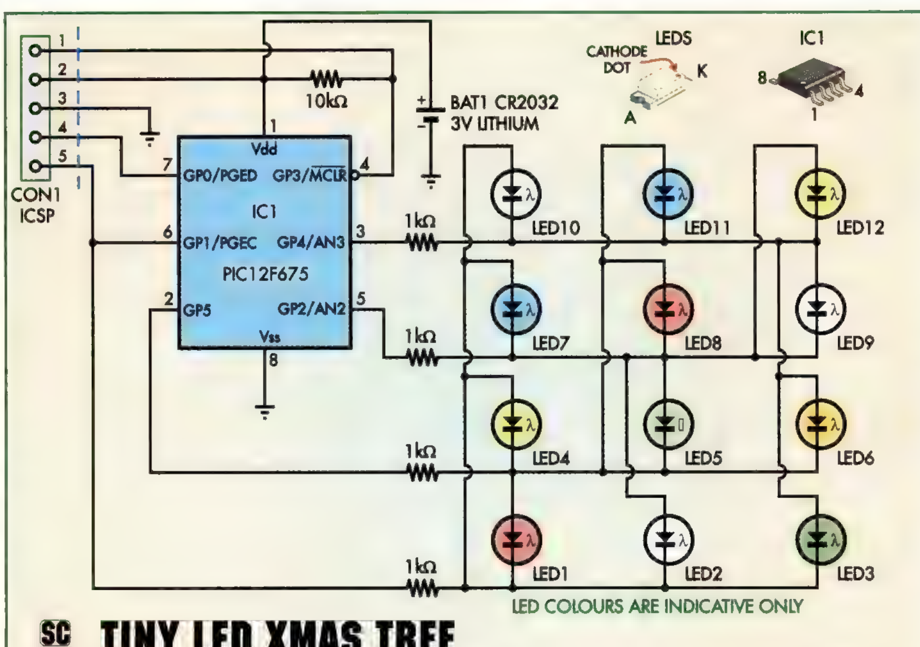
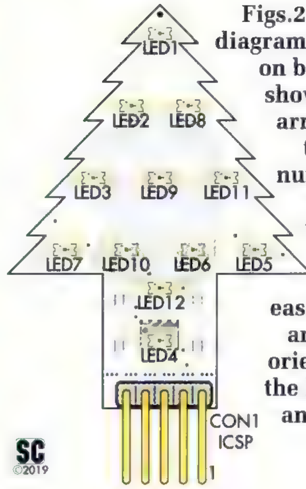


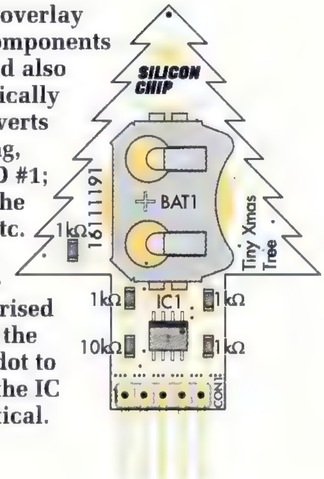
Fig.1: the circuit is simplicity itself, involving just one IC, five resistors, twelve LEDs and a lithium cell. Each LED is connected across a different pair of pins, via two 1kΩ series current-limiting resistors. The optional in-circuit programming header is on a section of the board that snaps off in case you don't need it. You can also fit it and snap it off after you have finished programming IC1.

LED	High pin	Low pin
LED1	GP5	GP1
LED2	GP2	GP1
LED3	GP4	GP1
LED4	GP1	GP5
LED5	GP2	GP5
LED6	GP4	GP5
LED7	GP1	GP2
LED8	GP5	GP2
LED9	GP4	GP2
LED10	GP1	GP4
LED11	GP5	GP4
LED12	GP2	GP4

Table 1 - LED drive pin combinations



Figs.2a (left) & 2b (right): these overlay diagrams show where to fit the components on both sides of the board, and also show how the LEDs are physically arranged. The software converts this into a simple mapping, numbering the top-most LED #1; the second row #2 & #3; the third row #4, #5 and #6 etc. This makes designing patterns in the software easier. All the LEDs are polarised and must be installed with the orientation shown (cathode dot to the left). The orientations of the IC and cell holder are also critical.



while it is possible to run LEDs directly from I/O pins in some cases, we decided to use series current-limiting resistors.

Each I/O pin can source or sink up to 25mA, and if the button cell had to supply this much current (even briefly), its voltage would sag quite badly, possibly leading to microcontroller glitches which would interfere with the pattern. This would also likely lead to a short cell life.

Software

The software is designed with low power consumption in mind, so the processor spends much of its time in sleep mode, only being woken occasionally by the "watchdog" timer. This is an essential part of our recipe for minimal power usage.

The software initialises the I/O pins and assigns its internal prescaler to the watchdog timer, allowing us to alter the prescaler and thus change the watchdog delay.

It then sets up an array of values containing the numbers of the LEDs that should be lit in sequence. The program then steps through this array, lights one LED and then puts the processor into sleep mode for 18ms. After this, the LED is switched off, and the processor sleeps for another 72ms.

The processor cycles through the array and repeats this sequence as long as it has power. Changing the pattern is as simple as changing the array in the code.

By having the processor sleep nearly all the time, the vast majority of the power used is consumed by the LEDs, with a small amount being dissipated in the series resistors and an even smaller amount by the microcontroller during the brief periods that it is active.

LED Charlieplexing

The technique we use for driving the LEDs in our Tiny Christmas Tree is called Charlieplexing, named for Charlie Allen of Maxim Integrated. Maxim is known for their LED driver ICs, such as the MAX7219 which we described previously in the LED Matrix Display Module article from June 2017 (siliconchip.com.au/Article/10680).

Charlieplexing, as the name suggests, is a variation of traditional multiplexing. We used Charlieplexing in our Digital Up/Down Timer project in the August 2010 issue (siliconchip.com.au/Article/240).

Traditional multiplexing arranges the LEDs in a grid, with one set of pins to drive the anodes and one set to drive the cathodes.

If you have 100 LEDs in a 10x10 grid, 20 output pins are required to drive them. Or 12 LEDs in a 3 x 4 grid would require a total of seven output pins; a bit difficult when you are using an 8-pin micro!

With Charlieplexing, each I/O pin can effectively be used to drive both a row and a column (except that it can't be both at the same time), so the number of LEDs that can be driven from the same number of pins is greatly increased. In our Tiny Christmas Tree, the four I/O pins can now drive 12 LEDs.

The biggest disadvantage of Charlieplexing is that you can't illuminate as many LEDs at the same time. With regular multiplexing, you can light up a whole row or column at once, whereas with Charlieplexing, you can only really light up one at a time.

Also, planning the wiring for such a Charlieplexing arrangement is tricky, especially as large arrays of LEDs are typically arranged in a grid, which lends itself well to the row/column principle of basic multiplexing. This also leads to increased software complexity.

For Charlieplexing, the I/O pins used need to be capable of being driven high, driven low and also being set to high-impedance. This makes it harder to use discrete transistors to implement such a scheme. Regular multiplexing requires the pins only to switch between high and low, or active and high-impedance, which is easier to do with discrete transistors.

Other restrictions apply to Charlieplexing. In particular, the forward voltage of the LEDs must be within a certain range. If the forward voltage of one particular LED is more than the forward voltage of some other pair of LEDs in the Charlieplex' matrix', current will pass through the other pair, leading to some LEDs lighting up when they should and some when they shouldn't.

Fortunately, our simple circuit does not suffer from this; any combination of red, yellow, green, blue and white LEDs can be used.

You might have trouble if you try to use an infrared LED, but we aren't sure why you would want to do that!

While it is possible to illuminate multiple LEDs at a time with Charlieplexing, we have chosen not to do so in this project. Simplicity is the first reason; there are restrictions on which LEDs can be lit together. By lighting one at a time, we do not need to consider that.

Lighting one LED at a time also reduces the peak current needed from the cell, which is vital for getting the most life out of the button cells. The usable mAh rating of button cells is considerably less at higher currents.

Tests on our prototype measured a typical average current draw of 70µA, which should allow weeks of operation from a fresh coin cell. That's well and truly enough to run the ornaments for the 12 days of Christmas, and beyond!

Our best estimate is that a new CR2032 cell with a nominal capacity of 240mAh will last from the start of December until around the middle of March, although we haven't tested this. That will mean you can take them down just before Easter!

We've chosen 1kΩ current-limiting resistors to give a long battery life and sufficient brightness for indoor use. If you want the LEDs to be brighter, possibly bright enough to be used in sunlight (but out of the rain!) then you can reduce these values.

We tested resistors as low as 100Ω, and the Tree worked fine, although we would expect its battery life to be proportionally reduced (to around a week for 100Ω).

Construction

To ensure that the Tiny Christmas Tree is, well, Tiny, we are using surface-mounted components. We have also done away with markings on the front of the PCB to give the Tree a more presentable appearance.

Thus there are components on both sides of the PCB. Fig.2(a) shows the top side component overlay, with Fig.2(b) showing the components fitted on the opposite side.

The SMD parts are mostly a large size, ie, 3216 metric (1206 imperial). IC1 is in an 8-pin SOIC package. All these parts are quite manageable, even with a fairly large-tipped iron.

Having flux paste and tweezers will make this much easier. Solder braid (wick) will also be handy if you end up bridging any pads. You might also use a small piece of adhesive putty (such as Blu Tack) to hold the PCB in place as its small size means it could move around easily while you're trying to line up the components.

Start by fitting IC1. Apply flux to the pads and note the orientation of the pin 1 marking on the IC. It needs to align with the notch in the silkscreen on the PCB.

Place the IC onto the pads and align it as best you can. Gently hold it in place with tweezers, then apply a small amount of solder to the iron tip and touch it to one pin of the IC. The flux will help pull the solder onto the pin and its pad.

Check that the other pins are correctly lined up with their pads. If they are not, grasp the IC with the tweezers and move it into place while using the iron to remelt the solder. Once the IC is correctly aligned, touch the iron to the remaining pins. You may need to apply more solder as it is sucked from the tip onto the pins and pads.

If you have a bridge between two pins, solder the remaining pins before attempting to remove it. Having all the pins soldered will help to keep the IC in the correct location.

To remove the bridge, apply some more flux to the top of the pins and press the end of a piece of braid against the pins with an iron. This should absorb any excess solder onto the braid, leaving just enough to maintain a good joint.

The next step is to install the resistors. There is a single 10kΩ resistor and four nominally 1kΩ resistors, none of which are polarised. Fit the 10kΩ resistor first, where shown. Apply a small amount of solder to the pads and hold the resistor in place with the

Parts list – Tiny LED Christmas Tree

(A kit is available from the Silicon Chip Online Shop; see below right)

1 double-sided PCB coded 16111191, 54mm x 41mm (green, red or white solder mask)
1 5-way right-angle header strip (CON1) (optional, for programming)
1 surface-mount coin cell holder [Digikey BAT-HLD-001-ND, Mouser 712-BAT-HLD-001 or similar]
1 PIC12F675-I/SN 8-bit microcontroller, SOIC-8, programmed with 1611119A.HEX (IC1)
1 10kΩ 3216 (1206 imperial) SMD resistor [Altronics R8188]
4 1kΩ 3216 (1206 imperial) SMD resistors [Altronics R8116]
12 3216 (1206) SMD LEDs (any colours) [Altronics Y1041, Y1056, Y1073, Y1079, Y1085]
1 CR2032 coin cell or similar (CR2025 is also suitable)

tweezers. Load up the iron with a small amount of solder and apply it to one pad; the solder should flow into the join.

Check that the part is within the pad markings and if not, adjust it. Solder the second pad. If you have the right amount of flux, the solder between the pad and component should look smooth and shiny. Have a look at the photos of the board to see how it should look.

Do the same for the remaining resistors. There are three more around IC1 and one up and to the left amongst the branches of the tree.

Now flip the board over so that you can fit the LEDs. The markings on this side are minimal, to avoid spoiling the visual effect. You might be able to see a small line indicating the LED cathodes. All LEDs should be mounted with their cathode to the left.

This is usually marked with a small green dot on the LED body, although it's best to verify this using a DMM set on diode test mode before soldering them. When the LED lights up, the red probe is on the anode and the black probe on the cathode.

You can fit any colour LED to any location. We tested one of our prototypes with a mix of white, red, yellow, green and blue LEDs and found that they all worked fine. If you use high-brightness types, then you will get the best results from the meagre current they are supplied.

These are fitted in the same manner as the resistors, although you may find it takes a little more heat to make the solder joints.

The coin cell holder should be fitted next. Check that the cell opening faces away from the resistor, as shown in Fig.2(b) and our photos. Otherwise, you might have trouble getting the cell in later.

The holder should be mounted similarly to the other components, with a small amount of flux paste to help the solder flow smoothly. You will probably need to use more heat than the smaller components. Tack one end, check that the holder is straight and symmetrical and then solder the other end.

If you can't get the specified coin cell holder, you can substitute a 40mm length of 0.7mm tinned copper wire. We tested this by rigging one up, and it worked well enough.

We started by bending the wire into a gentle curve in the middle, with a sharp 180° bend of approximately 2mm radius at each end. The bends give a bit more springiness and help to hold the cell in place.

To place the wire at the correct height to provide sufficient tension, we placed a spare PCB (standard 1.6mm thickness) between the Tree board and the wire. Once soldered and the weight released, the wire will spring back a small amount to allow a 3.2mm thick CR2032 cell to fit underneath.

Balance the wire on the PCB and apply a good amount of solder to each end to hold it in place.

With the soldering complete, remove any excess flux with an appropriate cleaning solution to ensure that the front of the PCB presents a clean appearance.

Important!

Coin cells (like button cells and other small batteries) can be dangerous if they are ingested. The Tree and any batteries that might go inside it should be kept well away from small children and babies that might (nay, WILL) try to put such things in their mouth at the first opportunity!

We found that it was tricky to remove the coin cell without something thin to push it out of the holder. If you have substituted a piece of wire for the cell holder, the cell will not be held as tightly. Nonetheless, children will find a way. So it's best to keep the Trees well away from children.

You might consider adding a little glue or silicone sealant to the side of the cell to make it harder to remove, or even wrap the tree in a piece of large-diameter clear heatshrink tubing, which would also provide a measure of protection against being dropped, getting splashed etc.

Programming

If you have a pre-programmed microcontroller (eg, from the Silicon Chip Online Shop), you don't need to worry about this step and can jump ahead to the completion step.

To program the PIC requires a suitable programmer, such as PICkit 2, PICkit 3 or similar. While a five-way header can be soldered onto the pads at the bottom of the PCB, you can also press it in place for the duration of the programming if you only intend to do this once.

Not having the header soldered in place will also make it easier to break off the tab later.

Load the HEX file (available for download from the Silicon Chip website) into your programmer application and plug the header strip into the programmer. The pin marked with the arrow symbol on the programmer should line up with pin 1 of the header. This is marked on the back of the PCB and also has a rectangular (instead of oval-shaped) pad.

Then press the button to program the PIC. The LEDs should start flashing immediately, if the programmer is set to allow the PIC to run after programming.

Unplug the programmer and fit a coin cell. Take care to avoid having a coin cell fitted while the programmer is connected, as most coin cells will not take kindly to receiving a charge from the programmer's 5V supply.

The LEDs should cycle up the Tree and from left to right. If one or more LEDs do not light up, check that they are correctly soldered and orientated.

If only three or six of the LEDs are lighting, then one of the resistors may not be connected correctly, or one of the IC's pins may not be soldered properly.

If the pattern seems to be random, then your LEDs may have a mark on their anode instead of their cathode, which unfortunately sometimes seems to be the case. In this case, all LEDs will operate, but out of sequence. The

only solution is to remove and reverse them all.

If you have a different problem, remove the cell and check your construction carefully before reinserting it.

Completion

Once IC1 has been programmed and all the LEDs are operating correctly, the programming header can be removed. You may wish to leave it attached if you want to reprogram the IC later (eg, to change the pattern) or use the header to apply power to the board.

We think that the tree looks nicer without it.

There is a row of small holes across the end of the PCB so that it can be snapped off cleanly. Before snapping, gently score or file along this line on both sides of the board, to break the copper tracks. If this is not done, the traces may tear and lift off the PCB, causing damage to tracks that you need for it to operate.

Once scored, snap off the end of the PCB with a wide-jawed set of pliers. You can then file down the rough edge; it's best to do this outside and with a face mask so that you do not inhale any fibreglass dust.

If you want the tree to stand up on its own, you could instead leave the bottom tab in place and solder a short piece of wire to the centre pad. This is connected to ground, so care should be taken that this does not contact any other part of the circuit.

Mounting

There are two small pads near the top of the PCB which are designed to allow the Tree to be hung.

A loop of wire can be soldered to the small, round through-hole pad right at the top, allowing it to be hung as a tree ornament.

The square pad on the back can be soldered to a safety pin so that the Tree can be worn as a brooch.

Changing the pattern

The source code is included with the HEX file download from our website. This contains project files which can be edited with Microchip's MPLAB X V5.05 or later (a free download).

The sequence of LEDs is programmed into an array near the start of the "main.c" file, so modifying the values within is the easiest way to change the pattern.

The pattern sequence can be made up to 255 steps long by changing the contents of the pattern[] array. The numbers refer to the physical position of the LEDs, with number 1 at the top, 2 and 3 in the second row etc. The number 0 can be used to have no LEDs lit for a step.

As mentioned earlier, our first prototype used 100Ω LED current-limiting resistors instead of 1kΩ. This made the LEDs much brighter, but the button cell did not last anywhere near as long. But if you just want the ornament to run for a few days over Christmas, that would be a good option.

Alternatively, if you have a source of 5V DC power, you can opt for the brighter option and power the Tree via pins 2 (5V) and 3 (GND) of the programming header, or via the coin cell holder pads.

You can also paint the PCB if you wish to change the appearance or add some colour, although it would probably be easier to purchase some different-coloured PCBs from our Online Shop.

As noted earlier, we will have boards with green, red and white solder masks available. SC

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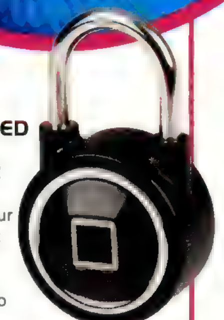

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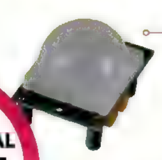

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DEADBOLT KIT WITH BLUETOOTH® TECHNOLOGY

Replace traditional door locks and enable users to gain access by using an App via Bluetooth® on their smartphone or tablet, or a unique passcode entered on the keypad. Generate codes on a smartphone. Long battery life. Fits doors 32-48mm thick. LA5095 **WAS $229**

Radio Frequency Identification (RFID)

- 10,000 USER CAPACITY
- IP65 RATED

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RFID ACCESS CARD READER

A robust mini access card reader which can be used as standalone or slave with an Wiegand 26 input access control system. Reads EM & HID RFID cards. Large capacity for up to 10,000 users. 12VDC. LA5351 **WAS $89.95**

- 2,000 USER CAPACITY
- IP65 RATED
- BUILT-IN BUZZER

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DIGITAL KEYPAD WITH RFID ACCESS CONTROL

Suitable to areas requiring stricter access control such as warehouse, bank, prison etc. Housed in a sturdy IP65 vandal proof zinc alloy case. Support up to 2,000 users. Indoor/outdoor mounting. 12-24VDC. LA5353 **WAS $129**

- 20,000 USER CAPACITY

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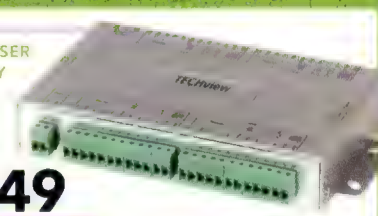

4 DOOR RFID ACESS CONTROLLER

Control up to 4 doors, 4 readers and 4 exit buttons. Perfect for large or small businesses with up to 20,000 users and permanent entry logging up to 100,000 times. Anti-passback. Multi-card entry. 12VDC. LA5359 **WAS $299**

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ELECTRIC DOOR STRIKE

Upgrade your conventional door locks to keyless entry electronic access. Suitable for narrower doors. Fail-secure model.
- 12VDC, 450mA

LA5077 **WAS $44.95**

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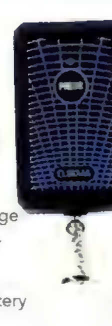

SINGLE CHANNEL KEYFOB REMOTE

Multi-purpose replacement remote control keyfob for garage doors or security gates. Single button control. 27MHz transmission.
- Requires 1 × A27 battery (not included)

LR8847

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NON-CONTACT INFRARED DOOR EXIT SWITCH

Replace your old push button switch to this infrared sensor switch to automatically opens the door with just a wave of your hand. Stainless steel plate with built-in LED indicator. 12VDC. LA5187 **WAS $69.95**

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ONE CHANNEL CONTROLLER

Multi-purpose replacement remote control for garage doors or security gates. 27MHz transmission.
- Requires 9V battery (**SB2423 $3.95** sold separately)

LR8827

What is an IP camera?

An IP camera is a networked digital camera that transmits data over a fast Ethernet link. IP cameras (also called "network cameras") are most often used for IP surveillance, a digitised and networked version of closed circuit television (CCTV).

The benefits over analogue technology include:

- **Remote administration from any location**
- **Send images and video anywhere with an Internet connection**
- **Adjustable frame rates and resolution**
- **Lower cabling requirements**
- **Support for intelligent video**
- **Digital zoom**
- **Progressive scanning**
- **2-way communications**
- **Sends alerts if suspicious activities are detected**

Customise Your Own Surveillance System

NEXTECH

QC3856 OUTDOOR USE

INDOOR USE

QC3858

1080P WITH INFRARED ILLUMINATION

Using the free iOS™ and Android Smartphone app you can connect to the camera and adjust camera parameters, review footage, etc. QC3856

WERE $129EA.

$99 ea

SAVE $30

1080P WITH PAN/TILT

Free iOS™ and Android app to remotely access the camera, pan, tilt, review footage, etc. using your Smartphone, iPad or Android tablet. QC3858

OUTDOOR USE

INDOOR USE

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1080P WITH LED SPOTLIGHTS

Infrared LED's automatically turn on in low light, with spotlights for illuminating a path for visitors and deterring thieves. Includes 2 way audio and phone push notifications. QC3857 **WAS $169**

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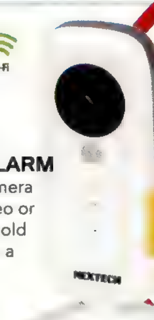
720P WITH INFRARED LEDS

Ultra-easy pairing setup. 2-way audio communication - so it can be used for access control functions. IR LEDs for night time use. Includes USB mains power adaptor and USB charging cable. QC3849 **WAS $69.95**

1080P WI-FI CAMERA WITH SECURITY ALARM



Use as a stand-alone camera to record audio and video or expand it with sensors (sold separately) to turn it into a security system.
QC3870 **RRP $129**

NEXTECH SECURITY BUNDLE DEAL

$149

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Includes QC3870 + QC3876 + QC3874 + QC3872

PIR SENSOR

- 12m detection range
- 1 year battery life

QC3876 **RRP $29.95**

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REED SENSOR

- Protects against intrusion

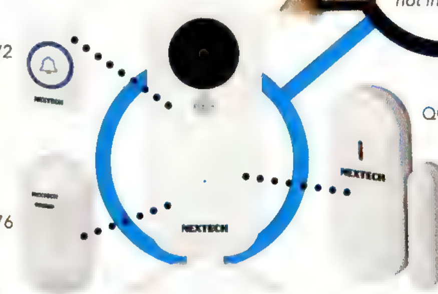
QC3874 **RRP $19.95**

View live footage on a Smartphone. *Smartphone not included.*

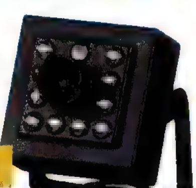
PANIC BUTTON

- Trigger security system in duress

QC3872 **RRP $19.95**



Covert Surveillance



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1080P MINI CAMERA WITH IR LEDS

Ideal for covert home security, retail stores or even in car or truck surveillance. Supports AHD, TVI, CVI & CVBS. Easy installation. IR for night vision. Up to 10m range. QC8651 **WAS $49.95**
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QC8202
Not to be used in areas where there is an expectation of privacy.

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MINIATURE 1080P WI-FI IP CAMERA

Stream and record video in HD with this tiny Wi-Fi IP camera. Record to microSD card (32GB card **XC4992 $36.95** sold separately). Infrared night vision.

- Only 42mm dia.

QC3862

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Plug PA3711
Socket PA3713

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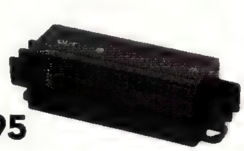

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Relays handle up to 10A current and are not suited for mains power.

SKILL LEVEL: Beginner

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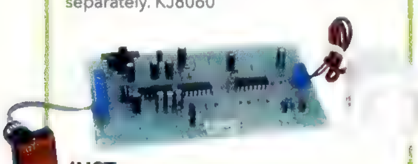

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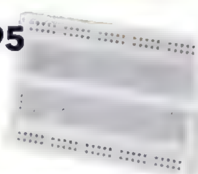

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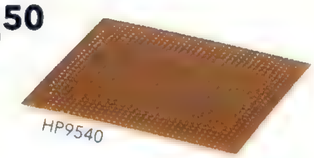

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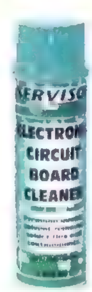

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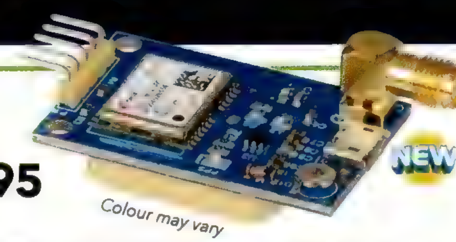

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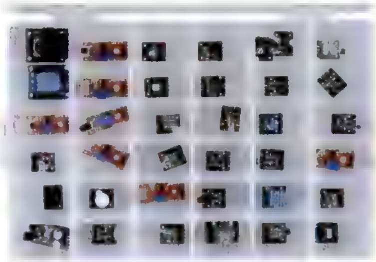

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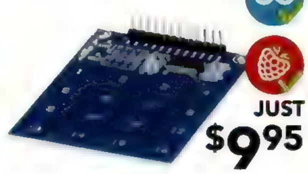

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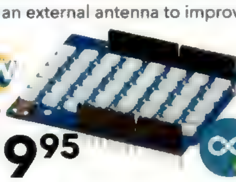

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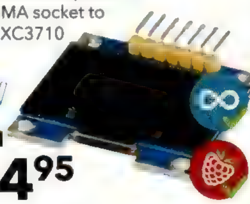

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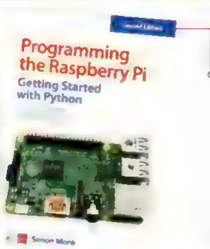

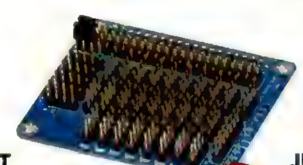

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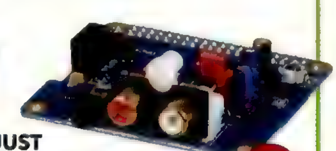

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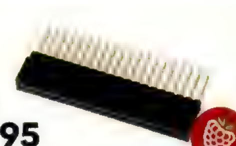

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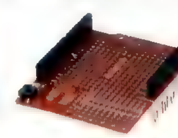

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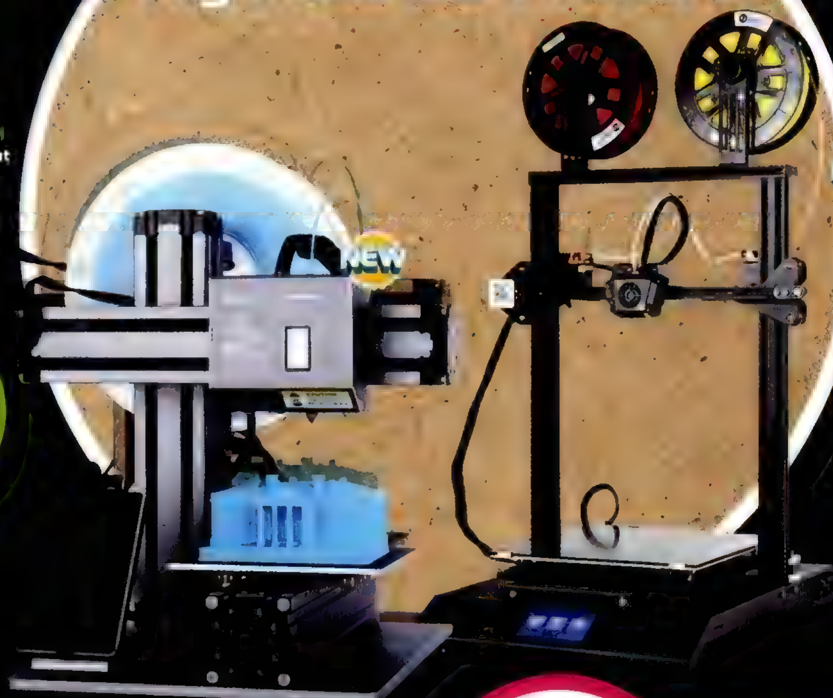

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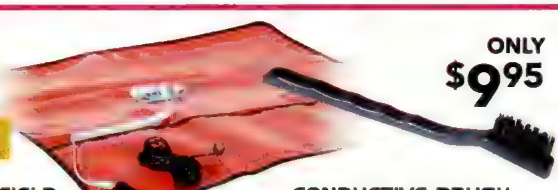

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SERVICEMAN'S LOG

The alarming false alarm system

Dave Thompson

I've written before about home alarms and the problems that DIYers like myself run into working on them. The main problem is that I don't know what I don't know, and given my proclivity to 'have a go', it's no surprise that I sometimes come unglued. The silver lining is that everything is a learning opportunity; next time I'll try again, and if necessary, bring in someone who knows what they're doing.

Items Covered This Month

- Alarm systems with false alarms are alarming
- Two Yamaha amps and a Bose FX unit restoration
- Behringer RX1202FX 12-channel mixer repair
- Rangehood repair

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This means – rightly or wrongly – that I sometimes try to do jobs usually best left to professionals. However, getting a professional to do the job doesn't guarantee that it's done right either! Admittedly, my expectations might be unrealistic. But if I'm paying (usually handsomely) for a job, I expect a certain level of competence when it comes to the final result.

I'll be the first to admit that I'm an average serviceman; I win on some repairs and fail at others. My Dad, and then the airline I served with, instilled in me the will and skills to do a good job, and this set my standards high. Given the environment at the airbase, and the number of people who worked there, it is inevitable that there would be others far more capable than myself.

Those guys studied hard, got licensed to the hilt and more often than not, saw out their careers pushing papers in technical support. Then there were the guys who weren't as 'book-smart', but who were very manually skilled.

I knew engineers who could weld wood to concrete without a visible bead, or strip jet engines or avionic systems, overhauling every component and then reassembling it all blindfolded (not that that was encouraged)!

I was somewhere in the mix; everyone had different skills, and with a bit of good fortune, we all ended up where we wanted to be, doing what we wanted to do. Now and then an extra-challenging job would come across the bench to spice up the workday. I sometimes miss being part of that environment.

Lately, I've encountered several 'professionals' where tool skills didn't seem to be part of their job requirements. It pains me to shell out for a job that, even when viewed with hindsight, we could have done ourselves; and sometimes done better.

I've had workers come to service appliances, repair water pipes and install fibre broadband and in all these cases, I reckon I could have done at least an equally good job.

I know about as much about plumbing as I do about mathematical formalism in quantum mechanics. But with all due respect to plumbers, charging $700 to zip-cut a metal pipe off and replace it with a plastic section over two hours is awfully steep. And the less said, the better, about the gas-fitter who scribed a divot into our brand-new benchtop when his power drill slipped.

~SHOPPERS WALKED PAST WITHOUT A RAISED EYEBROW

I could have fitted that hob, or done the pipes; I just wasn't "qualified" for the job.

These situations remind me of the old yarn about the boilermaker who was brought in to fix the misbehaving boiler on a steamship. He walked in, looked around for a couple of minutes, took out a tiny hammer and gently tapped a valve. The boiler then worked perfectly. The ship owner was irate to receive a $1000 bill for this fix, and asked for an itemised invoice. The invoice he received read:

Tapping the valve: 50¢
Knowing where to tap: $999.50
Total: $1000

So I guess my point is, you hire the professionals to do an easy job so that if it turns out not to be so easy, you don't get into a lot of bother. But it's still galling when someone charges you a lot to do a sub-par job, especially when you know you could do better.

Installing the old alarm system

When we moved into this house, we installed a security system. This was for our own peace of mind and also the safety of my tools and my customers' hardware in my workshop. (April 2018; siliconchip.com.au/Article/11033).

It is debatable whether a neighbour would even bother glancing at our residence if the alarm was blaring away. But it is nice to know that in a dimly-lit bunker somewhere across town, an operator is sitting at a console, waiting for our monitored alarm to go off, so they can send a security guard around and charge us a hundred bucks for the privilege!

If I hear a nearby alarm sounding, I always wander down the street and have a look at what's going on, even though I'm not sure what I could do if I do find something amiss.

I've accidentally set my car alarm off in public several times. On one occasion, I'd locked myself out of it in a supermarket car park and was trying to break in. Shoppers walked past without a raised eyebrow, though admittedly some did look annoyed at the noise!

My first stop was the alarm monitoring company we'd used for the last 20 years. They had provided our original alarm system by way of a deal where you got the system free if you signed up for three years monitoring at a buck a day. We'd moved that system a couple of times over the years and weren't keen on moving it again.

The bad news was the alarm companies don't do those deals anymore. I would be looking at "about a grand" to have a basic system installed and configured by Chap and Bloke, the two overall-clad likely lads who were contracted to do this company's alarm installations.

I'd had dealings with these guys in the past and wasn't too impressed with their work, so I thought I'd check the internet first.

There are literally thousands of alarm systems on AliExpress (one of my favourite websites back then), some cheap and some costly; the biggest problem was which one to choose. Talk about upskilling by proxy; I had to learn and translate a whole raft of new acronyms and technical double-speak.

I also had some strict requirements; many of the newer systems used only SIM cards and the digital GSM (cellular) network to send data to the monitoring company.

Not only does this involve an ongoing cost for any calls made from the alarm, but back then, the monitoring company couldn't accept signals sent this way. So we had to ensure any alarm we installed used the increasingly 'old-tech' copper-wire based PSTN (Public Switched Telephone Network) system.

This proved to be no real problem as many compatible PTSN systems were available, and the majority of those systems used 433MHz wireless technology to connect sensors to the 'base' unit. This was appealing on many levels, not the least of which is that I am getting too old to be crawling around in the roof or under floors to route wires.

I ended up purchasing a mid-level digital base unit with both PTSN and GSM capability, along with suitable wireless pet-sensitive PIR sensors, a couple of photo-electric smoke detectors and some magnetic door/window switches.

I could have up to 99 zones with this system, and while this was a few more than I needed right away for Casa Thompson, it would allow me to expand. Who knows, I might eventually add 92 more rooms to my house. Any more than that and I would need a new alarm system!

Installing this system was as easy as it sounds, with the majority of the work going into deciding where to put the sensors and screwing their mounts to the walls or doorframes. Then it was just a matter of programming the base unit and adding the sensors to it.

I wired in a copper phone line using the supplied cable, which I first had to modify by cutting off the original RJ11 plug and crimping on a kiwi Telecom BT-style connector. I had a spare SIM, so for 'belt-and-braces' monitoring, I put that into the system as well.

I then encountered the first hiccup: the new panel wanted to know my monitoring company's phone number and my customer number, neither of which I knew. The only way to get this information was to call up the company, and of course, they weren't about to dish that information to just anybody, and (quite rightly) didn't want some cowboy messing around with their system.

In the end, I had to book Bill and Bob to make a visit, just to watch them press a couple of buttons and make a test call to the monitoring centre. *Note to self: make sure to factor another $200 into the cost of any future alarm system.*

For the most part, this alarm worked well. It came with four keyfobs for wireless arming and disarming, and these are extremely handy; especially because after a few years, I forgot what codes I originally programmed into the panel for manual disarming, since I never used them!

A flawed system

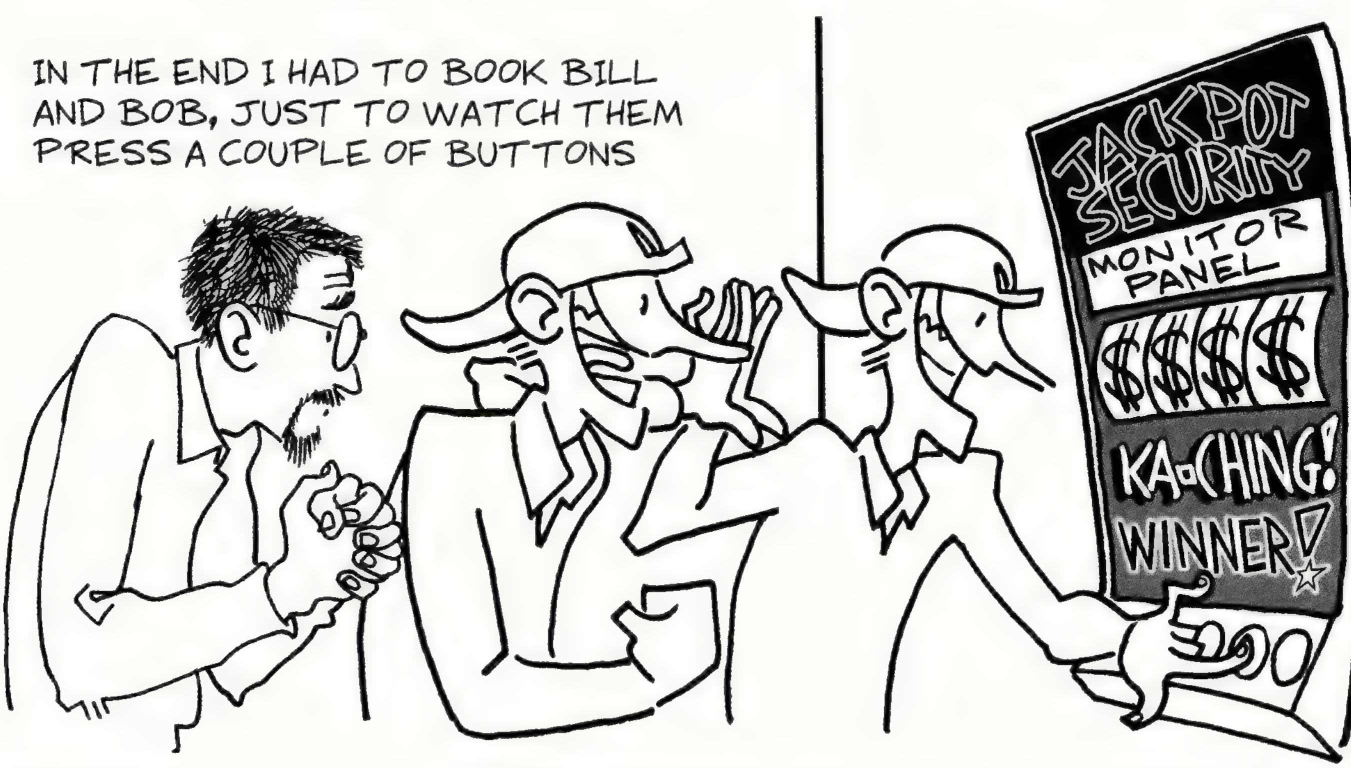
One of the big downsides is replacing batteries in the sensors; the PIRs use that old standard, the 9V battery, but the window and door sensors chew up those little 12V 23A-style buggers, and neither are cheap to replace. *Note to self: factor in many more dollars for batteries for any future wireless alarm system.*

Replacing batteries is to be expected, but as the voltage drops, some sensors get unstable, so we were continually having false alarms. In fact, this was usually how I found out that a sensor battery was going flat. Being rudely woken up at 4am by a shrieking piezo siren is not my idea of fun!

Being at home when a false alarm happens is one thing; being out and about when it happens results in a whole other set of problems. The alarm calls the monitoring company, telling them what zone is triggered and what type of emergency it is (fire, intruder, panic etc). It also calls my mobile phone via the SIM with a pre-recorded message with similar information.

The problem, as I discovered, is that the monitoring company usually get straight on their phone to call my registered number to report the alarm going off. But they get a busy signal because the alarm system is repeatedly calling me, tying up my phone. If I didn't answer, they'd send a security guard around and charge us the fee.

This can be a real pain, especially as Murphy's Law dictates this happens only when I'm in an important meeting, driving, or sitting in the dentists' chair. I soon reconfigured things to make this process smoother. Another lesson learned. *Note to self: factor in*



many potential visits from security guards in any future wireless alarm system.

Long story short, I got sick of constantly replacing batteries and paying security guards to tell me we had another a false alarm. I can't remember our old wired system, which we'd used for decades, ever going off (unless we tripped it accidentally). So I resolved a few months back to look for something similar to that and replace this new-fangled-but-flawed wireless thing.

I should also add that recently, the monitoring company let us know they had upgraded their system and could now do GSM signal monitoring. While this meant we might be able to ditch our old copper phone lines, they also said it would incur higher per-call costs than what we currently pay.

I briefly pondered how that worked, since we paid for any alarm-generated cell-phone calls anyway, but gave up and decided to stick with the monitoring system we already had.

Fed up with wireless hassles

I found a new alarm system on AliExpress almost identical to our old 8-zone wired system, but with 16 zones, a lockable metal box and PSTN dialling. It was quite reasonably priced and included a couple of fob remotes for wireless arm/disarm.

I could also pick whatever sensors I wanted to go with it, and opted for three pet-sensitive and three 'normal' PIR/microwave combination sensors. These are Canadian-made, and apparently they have the lowest false-trigger figures in the business. I also got two smoke detectors and an extra keypad. All I'd have to add is a 12V SLA backup battery and some cable; I already had a 100m roll.

One obvious downside to this decision is the requirement to run those cables. This is usually not too much of a hassle in any normal house (at least here in New Zealand) with reasonable roof or underfloor space.

However, our house was converted from a single to a double-storey home 30 years ago. So much of the ground-floor ceiling space needed for routing cables has a whole other house sitting right above it, leaving almost no usable gaps.

While there is a very narrow crawlspace around the perimeter of the roof, I (and a builder friend) pondered this sensor location and cable-routing problem for weeks. We eventually decided that the only way was for one of us (that means me) to suit up, get into the roof space and to probe aptly-named fish tape (or fishing rods) through any gaps we could find between the floors.

Hopefully, we could route the wires as close to the ideal sensor positions as possible. If the worst came to the worst, I'd run the cables out through the roof tiles and around the eaves. *Note to self: before buying wired alarms, check out potential cable access problems!*

I'm not claustrophobic enough to have a problem crawling around inside the wing tanks of aeroplanes, but that was 35 years ago, and I had proper gear then. Wiggling through dark, spider-web and mouse dropping-infested gaps I can barely fit my shoulders through while dragging a long fibreglass pole is not how I pictured spending my increasingly autumnal years.

Someone had to do it, though. I am happy to report that with some surprisingly agile gymnastics and inspired-but-educated guesswork from both of us, we were able to run all the cables we needed to the positions we wanted. We only had to drill one hole in a less-than-ideal position, around 50mm away from where we wanted it.

While I was up there, I ran Cat6 network cabling out to my workshop and a couple of other rooms I wanted connected, so we got a lot done in one day. *Note to self: allow several days for physical recovery after cabling work.*

I mounted the alarm box by the access door in the roof space, which is a natural junction of all the cables coming from the sensors. I mounted a couple of cheap LED lights up there too, which made connecting up the sensor wires a lot easier.

This was all relatively straightforward work. But I did need to ensure the sensors' operating mode (normally-open or normally-closed, set by jumpers on their PCBs) matched the panel configuration.

Normally-closed operation requires a so-called "end-of-line" resistor (2.7kΩ) wired in series with the sensor's 'hot' lead, while a normally-open sensor requires the resistor to be wired in parallel with the hot and ground leads. The alarm's user manual had these two diagrams transposed, but I eventually worked it out.

I still had to deal with those unknown monitoring numbers. Luckily, I found them in my old wireless panel, so retrieving them and programming them into the new system was a cinch. It's been working now for months and not one false alarm, so I'd call that job done, and not a 'professional' in sight (thank goodness?).

Yamaha amplifier and Bose guitar effects unit restoration

D. D., of Petrie, Qld is a serial repairer and recently managed to easily fix two different Yamaha amps and a guitar effects unit, two of which had already been relegated to the tip! That's a pretty good effort and here is how he did it…

The local tip has a recycling section where you can drop off your unwanted gear to sell to people who can use it, but their policy recently changed, and they no longer allow mains-powered equipment to be sold in this manner. But as I was recycling some bits and pieces, I happened across a Yamaha RX-V457 7.1-channel surround receiver.

A tip worker saw me looking at it, so I asked him if I could have it. He said no (with a wink), but if he doesn't see me take it, then he can't do anything about it. He then walked away.

So I became the proud new owner of an amplifier. I got the unit home, plugged it in, and nothing happened. So, Google to the rescue. There is a common fault with this amplifier, a capacitor on the inlet power circuit board goes bad. I tested capacitor C4 and found it much lower than its rating of 22nF, 630V.

I replaced it with a new one from Jaycar and the amplifier now sounds fantastic, although I did have to buy

a remote control, which was the most expensive part of the repair!

Here's another story of a tip rescue. My brother-in-law's brother works at his local tip and picks up bits and pieces all the time. Lately, he happened across a Boss ME-50 guitar multiple effects unit. These are pretty cool and have pretty much everything a guitar player could want, with some 22 effects.

The unit had no (or very low) output signals. Disassembling it took a while due to the 20 odd potentiometers holding it together. I found a very nice looking PCB populated with SMDs. A quick internet search revealed the service manual and a circuit diagram.

I applied a sinewave signal to the aux input using my smartphone. I could see the signal going into the circuit but nothing coming out. While looking at the diagram, I noticed there are muting transistors on the outputs of all the channels, so I lifted one of the legs of all of these SMD transistors, but there was still no output.

Next, I tried removing each op amp one by one to see if one was causing the problem. As luck would have it, the very first op amp I lifted (IC6, NJM4556) solved the problem. It appeared to have a short circuit across its inputs, which was shunting the input signal to ground for all the op amps. As soon as I replaced that IC, the whole thing worked.

My third repair was of a Yamaha RX-V2067 7.2-channel surround sound amplifier that was given to me. It would turn on but then switch itself off after a second or so. I initially thought great another easy fix with a faulty capacitor on the power board, but it was not to be.

So I downloaded the service manual and put the unit into service/no protection mode. The unit prompted me with an error code, "PS2_PRT 168H". A perusal of the manual showed that this error code is related to the voltage rails labelled, ±12V, ±12RY, +5A, +44V and +5DK.

The schematic showed the regulators for three of these rails were on the PCB labelled "video 2", which is right at the bottom of the unit, so after removing four PCBs and many screws and unplugging many connectors, I got to those board. I set it up on the bench with my bench supply and measured all the voltages. They were all in spec. I then re-assembled the unit and powered it on, testing all the other rails; they were all in spec too.

I scratched my head and had another look at the schematics. The PS2_PRT line is a sum of all the above voltages via a resistor voltage divider network, resulting in a voltage going into the A/D converter which should be around 1.6V but I measured 2.2V.

I removed the PCB labelled "video 2" again and started checking the resistors related to this voltage divider network. I found one which measured 70kΩ, but it should have been 47kΩ. These are all small 0603-sized SMD resistors.

On removal of the suspect resistor, I tried to measure it again and found it open circuit briefly, before it flew off somewhere, yet to be found.

I didn't have any 0603-sized 47kΩ resistors in my home stockpile, but I had a couple of 0.25W axial versions which, with a bit of lead manipulation, I soldered to the pads. After reassembly, the PS2_PRT line now reads 1.5V and the unit no longer goes into protection mode.

Unfortunately, it only worked for a couple of days before all sound disappeared. I put the unit into service mode again and found that I could get sound out of the speakers using the service modes A2: analog direct test and the A7: manual test. So I knew the amplifiers were still working.

I then used my phone as a signal generator and fed signals into all the channels one by one. They all worked on pure direct and A2 test mode. So all inputs and outputs were working. But there was a fault when the DSP function was switched on.

I started to follow the signal and found that nothing was coming out of IC811, a PCM1803 analog-to-digital converter (on the Function 3 PCB). Replacing the chip permanently fixed it.

Behringer RX1202FX 12-channel mixer repair

A. M., of Port Macquarie, NSW had to go into full sleuth mode to fix the power supply of a fancy mixer. Several parts had failed, and not just the usual culprits...

The RX1202FX is a rack-mountable 12-channel mixer with an integrated effects unit, designed by Behringer in Germany but made in China. The mixer arrived with no signs of life at all. My initial thought was that it was likely due to a failed power supply or fuse.

Of course, a failed fuse is usually a symptom of another problem and replacing the fuse won't necessarily fix it.

The mains fuse is located in an integrated IEC socket. Prising this open and testing the fuse showed the fuse to be intact, so a more a time-consuming repair would be required.

Opening the unit up revealed a front panel PCB, rear panel PCB and a small switch-mode power supply. The front and rear PCBs are connected via three ribbon cables, glued in place with hot glue. The power supply is mounted vertically between the front and rear panels with an output connector linking to the rear PCB.

Removing the power supply board involved undoing two screws, disconnecting the output connector on the rear PCB and desoldering the mains input cable from the rear panel switch and Neutral connection.

As is usual with a switch-mode supply, your mind immediately jumps to the capacitors as the source of the fault. I thought it would be an easy repair; just replace the dried-up electrolytics and it will work again.

Visual inspection of the supply, once it was removed from its aluminium heatsink/mounting frame, did not reveal any catastrophic damage, but did show it provided multiple supply rails and was designed by Behringer (many equipment switch-mode power supplies are generic devices made by third parties).

An internet search indicated that this supply was used in a few different Behringer mixers, but a complete replacement supply did not seem to be available. The search did yield a schematic, though; the commentary with the schematic was not in English so it may or may not have been an official diagram.

But it did match the part numbers and values and general configuration of the supply, and indicated the output voltages. The PCB silkscreen gave the component values as well as part numbers but not the output voltages.

Powering the supply up outside the mixer showed that all the supply rails were absent and the big input filter capacitor stayed charged once the mains had been removed. Being bitten by the 340V DC on these capacitors is something you always remember and good quality capacitors with no load can hold a charge for a long time.

The capacitor keeping its charge was a clue that the primary side of the supply was not switching. The two small electros on the primary side are were wedged between the large filter capacitor and the transformer. Both tested OK with the ESR meter and measured a reasonable capacitance in circuit.

All the surface-mount resistors on the primary side of the supply seemed to match both the schematic and their values, measured close to the markings on the PCB, except for R5. This is a 10kΩ surface-mount resistor between the X pin on the switching regulator IC (a seven-pin TOP245YN) and ground.

I desoldered R5 to check it further. It was apparent that the regulator had an internal short between the control input pins, damaging R5; strangely, the switching device had not failed. My previous experience with these devices is that the output device usually fails short-circuit.

While awaiting a replacement regulator, I decided to check the rest of the PCB and found both the 100nF X2 capacitors on the input filter to be under 10nF. While you would not expect that to stop the supply working, replacing them is easy and the designer of the supply put them there for a reason, so I did so.

The replacement regulator arrived and was duly fitted. The excitement of powering the supply up again was short lived when the 15V rails were sitting at 21V and the 12V rail was sitting at 19V. The 5V rail was correct; it was regulated off the transformer secondary with its own 7805 linear regulator, so this was to be expected.

At this point, at least the primary side of the supply appeared to be working correctly; no smoke, no explosions, just a little too much voltage on the secondary.

After sleeping on the problem, I thought that maybe the excessive output was due to a lack of load; after all, once in the mixer, the supply would always be loaded by the rest of the circuitry and the voltage would drop.

A dummy load was hastily knocked up from some resistors and the supply fired up again. This slightly reduced the loaded rails but they were still nowhere near 15V and 12V.

Clearly, the feedback path between the low voltage section of the supply and the control TOP245Y was not acting to regulate the output voltage. As is common on this type of supply, the feedback path consists of a voltage divider off the 15V rail, a TL431 shunt regulator and a 4N35 optocoupler to isolate the signal between the primary and secondary.

The voltage divider and filter capacitors all tested within acceptable tolerances and the reference pin on the shunt regulator voltage was close to the expected value given in the data sheet. Static tests with a multimeter suggested that the optocoupler had not catastrophically failed.

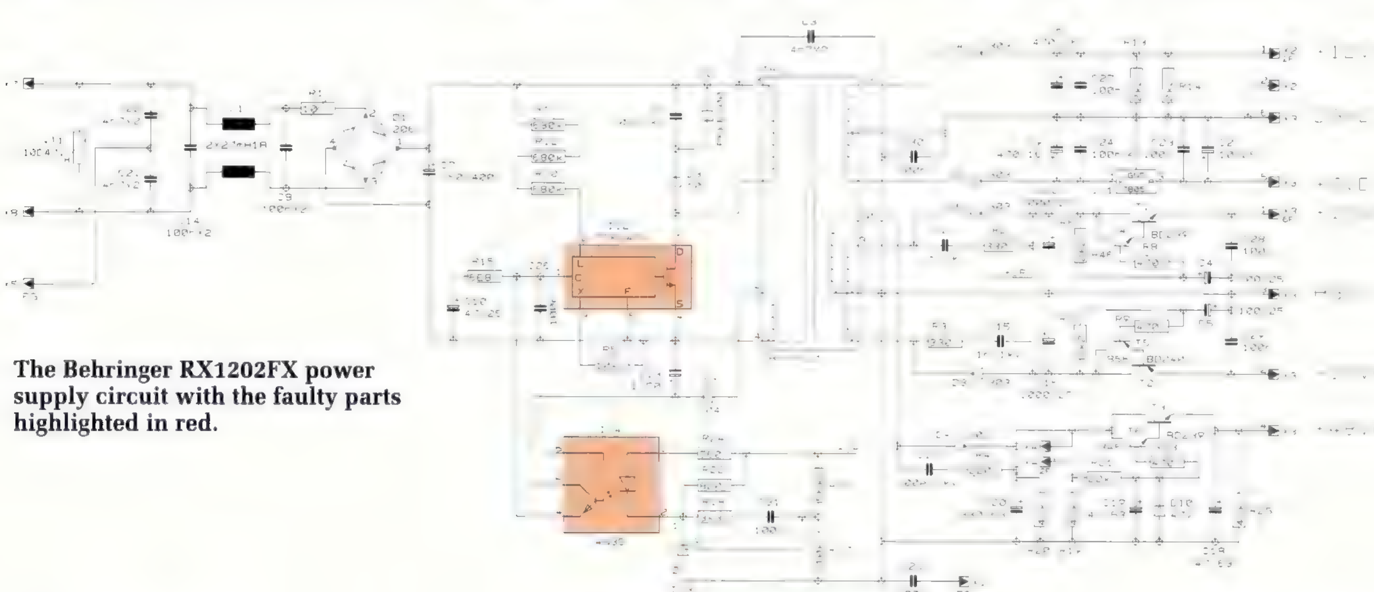
At this point, it was tempting to load the parts "shotgun" and replace everything on the board that had not already been replaced, as this would be quicker than further analysis and fault finding. But having heard stories of failed optocouplers and there being a general distrust of them amongst some parts of the design community, plus having plenty of spares, I rolled the dice and decided to replace the 4N35.

This was the magic that finally reduced the rail voltages to within normal limits. The unanswered questions now are about the chain of events which caused the supply to fail; was there a long-term over-voltage condition before it finally failed? Could this have damaged other parts of the mixer?

Due to the length of the interconnecting cables within the mixer, the only way to test the other boards was to fully reassemble the unit. Once assembled, the mixer powered up correctly and the expected LEDs on the front panel lit up. The next test involved injecting a sinewave into each channel and looking at the output on the oscilloscope and checking the response of the controls.

This was a time-consuming job on a 12-channel mixer but it revealed no apparent damage with a clear sinewave on each output matching the input, allowing for the effect of the controls. A final test with some music and an amplifier was anticlimactic, with all controls working as expected.

The reason for the failure of the switchmode regulator and optocoupler will have to remain a mystery. I speculate that the reduced capacitance of the input filter capacitors could have made the supply susceptible to mains-born transients, even though it appears well protected with



The Behringer RX1202FX power supply circuit with the faulty parts highlighted in red.

a metal oxide varistor (MOV) across the input.

Rangehood repair

R. G., of Cooloola Cove, Qld got sick of failing switchmode power supplies and decided to take an old school approach to repair a dead rangehood instead. This is what he did...

I have been retired a long time and do very little electronic work these days, but an old friend called to tell me that her rangehood no longer worked. As I had helped install it a couple of years ago, and as they could not get anyone to fix it, I said that I would have a look at it and see what I could do.

This is one of those rangehoods that has a front glass panel that curves up from the wall at the back of the stove to the top of the rangehood some 700-800mm above. The lower glass panel is fixed while the upper one swings out on hinges, and is opened by a 24V electric actuator. It also has the display and three touch buttons on it.

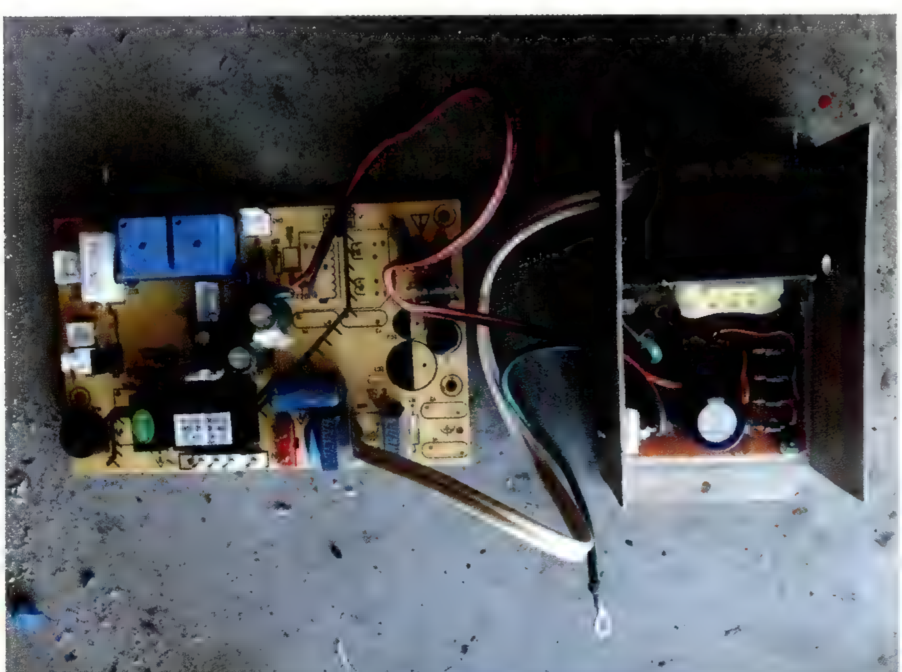
Since the rangehood would not operate at all, the first problem was to get it open to get at the control board. To do this, I removed the screws at the top of the rangehood to release the hinges holding the upper glass panel. Unfortunately, I still could not get my hand in far enough to remove the pin that releases the panel from the actuator.

I then noticed four screws in line with the actuator, further back on the top of the rangehood. Releasing these enabled me to get the panel far enough open to remove the pin. I then disconnected the wiring from the display and put the glass panel somewhere safe. The actuator then fell to the bottom of the metal box with a loud bang, but fortunately, it did not do any harm.

With hindsight, I should have removed the screws on the actuator first. That way I could have opened the glass panel on the hinges, which would have given me enough room to hold the actuator with one hand while I removed the pin with the other, enabling me to put the actuator down more gently on to the bottom of the box.

It was then only a matter of undoing three more screws and removing the lower glass panel to gain access to the workings. I removed two screws so I could lift off the black plastic cover over the controller board. I could see a switchmode power supply at one end with the fan control relays along the top. The remainder of the box contained the control electronics.

A test showed that there was 230V AC on the top of the board, but zero volts on the rectifier diode cathode connected to the transformer. I decided to take the control box off the wall and bring it back to my workshop for repair.



A new linear power supply (right) was made using a transformer, rectifier, regulator and some capacitors on a piece of veroboard. This was then mounted on a piece of aluminium and connected to the failed board for testing.

In my experience, these switchmode power supplies never last long when operating continuously, especially in a hot environment like in a rangehood. With it on the workbench, I unplugged all the cables and undid two more screws, allowing me to remove the control board.

I found that a low-value resistor in the 230V supply line was open-circuit, having acted as a fuse. I replaced this as well as the two high voltage electrolytic capacitors. One capacitor was open-circuit and had leaked out some of its contents. But even after those replacements, I still could not get any power out of it.

I then connected my bench power supply to the cathode of the rectifier diode. The supply uses 25V DC rated electrolytic filter capacitors, and contains 12V relays, so I thought that I would play safe and set it to 12V with a maximum current of 300mA. It then powered up and everything worked fine. The 24V actuator seemed to work even with the 12V supply.

The fan was not running because I had unplugged the unit from the mains. However, I could hear the relays click when I changed fan speeds.

A search of my junk box revealed a suitable power transformer, four 1A rectifier diodes, a 2500µF 25V electrolytic capacitor, a 7812 regulator, plus a few smaller capacitors and a piece of veroboard. I used these components to build a new linear power supply for the rangehood and mounted it into a piece of scrap aluminium that I had bent up.

I then removed most of the parts from the switchmode power supply, including its transformer and inline filter. I left the transient suppression components in place. I also removed its rectifier diode. I wired up my new supply, tested it to make sure that all was safe, plugged it into the GPO, and away it went, good as new.

I just had to fabricate a proper metal enclosure for the supply, which I pop riveted to the back of the rangehood box. The new power supply simply slides into this case and is held in by two screws so that it can be easily serviced. After reinstalling the rangehood, and putting it back together, my friends were pleased that it was all working again. **SC**

Part 2

High Power Linear Bench Supply

Last month, we introduced our new Linear Bench Supply, capable of delivering 8A at 45V or 2A at 50V. It's based around a 500VA toroidal transformer, a PCB control module fitted to a finned heatsink and two thermally controlled fans to keep it cool. These all mount in a metal instrument case. This month we cover the assembly and testing details of the PCB module.

There are quite a few steps involved in building this Supply, but none are terribly complicated. So if you follow our instructions, you shouldn't have any trouble getting it to work and ensuring that it's safe.

You'll need most or all of the parts in the list at the end of this article, so the first job is to gather those.

There's a bit of screwing, drilling, tapping and cutting needed to complete the hardware side of this project. Ideally, you should have a drill press, although you can get away with a decent hand drill.

You'll also need assorted drill bits, an M3 tap set, files and a hacksaw on hand.

Around half the assembly time is in building the control module, with the other half preparing the case and putting it all together. We'll have the case assembly and wiring details next month. This month's article concentrates on building that control module.

We've made it as easy as possible by using almost entirely through-hole parts and mounting them all on a single PCB. So let's get started building it.

Construction

Before mounting any parts on the control board, use the blank PCB and some of the other parts to mark out where holes will need to be drilled on the heatsink. The hole locations are shown in Fig.5, but it's better to use the actual PCB and devices to determine where to drill.

Start by fitting the PCB with the 9mm tapped spacers at each corner. Then temporarily place transistors Q3, Q4, Q5, Q6, Q7 and REG3 into their respective mounting holes, but don't solder them yet.

by Tim Blythman

Place the acrylic spacer under the heatsink to lift it up by 3mm, then centre the PCB on the face of the heatsink.

Making sure that each component is sitting up straight and at the same height, mark where the centre of each mounting hole sits on the heatsink (eg, using a felt tip pen).

Hold the bridge rectifier in place above the main devices, centred on the heatsink (see photos) and mark its mounting hole too.

While you're at it, use the acrylic insulating plate to mark out the positions of the four mounting holes on the underside of the heatsink, two on each side.

Now take the heatsink away and carefully drill all the marked holes with a 2.5mm bit to a depth of at least 6mm (or deeper if you don't have an

M3 finishing/bottoming tap), making sure they are drilled perpendicular to the face of the heatsink. Use kerosene or light machine oil to lubricate the drill bit and regularly clean out swarf.

Once all the holes have been drilled, tap them for an M3 thread to a depth of at least 6mm, again using plenty of lubricant and regularly clearing swarf from the tap.

Be careful not to use too much force to turn the tap, or you could break it, ruining both it and the heatsink.

As long as you regularly remove the swarf and re-lubricate the tap and hole, a consistently moderate amount of torque should be required.

If you do encounter increased resistance, unwind the tap a little bit and then try winding it clockwise again. If the resistance is still there, take it out and clean and re-lubricate the hole, then try again.

You can use a finishing tap to get the tapped holes to the required depth, or drill them a bit deeper and use the intermediate tap to cut threads at least 6mm into each hole. When finished, deburr all the holes and clean out all the swarf.

You may like to wash the heatsink with soapy water and let it dry off to get rid of some of the lubricating oil and the remaining swarf.

Before proceeding, it's also a good idea to use the bare PCB to mark out where its mounting holes will go in the bottom of the case.

Use the heatsink acrylic spacer to do the same for the four heatsink mounting holes, and position the mains transformer as shown in the photos, to mark out its central mounting hole.

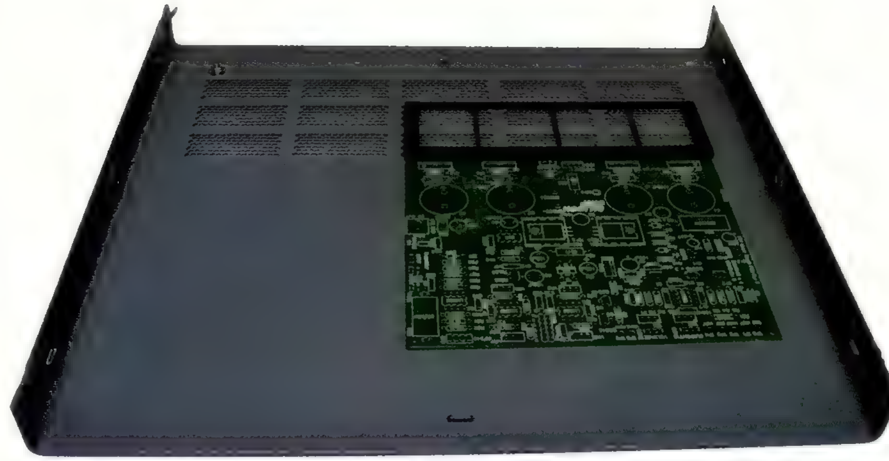
Make sure you leave enough space behind the heatsink fins for the fans. The fins should be around 45mm from the inside rear of the case.

PCB assembly

With that out of the way, we can now proceed to assemble the PCB using the overlay diagram, Fig.6, as a guide.

The Bench Supply is built on a double-sided PCB coded 18111181, measuring 150 x 120mm. The following description assumes the PCB is orientated as shown in Fig.6, with the heatsink mounted devices at the bottom edge.

There are two surface-mounted parts on this PCB, which should be fitted first. These are the 15mΩ shunt resistor and shunt monitor IC4, in an



It's a good idea to use an unassembled PCB and the acrylic heatsink spacer as a template to mark the mounting hole positions inside the case bottom. It's easier to do this now, rather than later!

8-pin SOIC package, which is mounted near the shunt.

Start with IC4. Apply flux paste to its pads, then locate IC4 over them. Make sure that its pin 1 is orientated so that it's closest to the shunt pads. Pin 1 is typically marked with a dot or divot on top of the IC package and a bevelled edge on that side.

Once it is in the correct location, solder one of its pins. Check that all of its pins are lined up with their pads. If not, re-heat the solder joint and gently nudge the part into place with tweezers.

Once you are happy that the part is aligned and flat against the PCB, solder the remaining pins by applying some solder to the iron tip and carefully touching each pin in turn. The solder should flow from the iron to the pin. Once the other pins are soldered, go back and re-touch the first pin.

If you are having trouble, apply some more flux. Excess solder can be removed with solder wick and a bit of extra flux paste. If a bridge occurs, don't remove it right away, but solder any unsoldered pins first. Then use the wick on one side at a time to remove any bridges.

The shunt is the next part to be fitted. It is relatively easy to solder but is connected to a wide power trace, so it may need a bit more heat. It is not polarised.

Apply solder to one pad, then rest the part on top and apply heat again to allow the part to sink into the solder and down onto the pad (pressing down on the part with tweezers helps with this process).

When the first solder joint is good, solder the other side, then go back and re-touch the first joint.

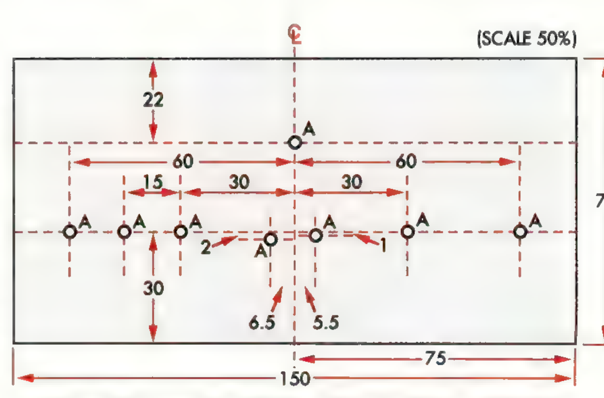
With these two parts in place, it's a good idea to clean up any excess flux on the PCB using isopropyl alcohol or a specialised flux remover.

Through-hole parts

You can now fit all the smaller axial parts, ie, resistors under 1W, zener diode ZD1 and small signal diodes D1-D4. Make sure that the diodes are orientated as shown in the overlay diagram.

While the resistors have colour-

Fig.5: a half-size drilling template for the heatsink. All holes are drilled and tapped for an M3 thread, to a depth of at least 6mm. While this should give you an idea of what to expect, as mentioned in the text, it's better to temporarily insert the actual devices and mark where their mounting holes sit if possible.



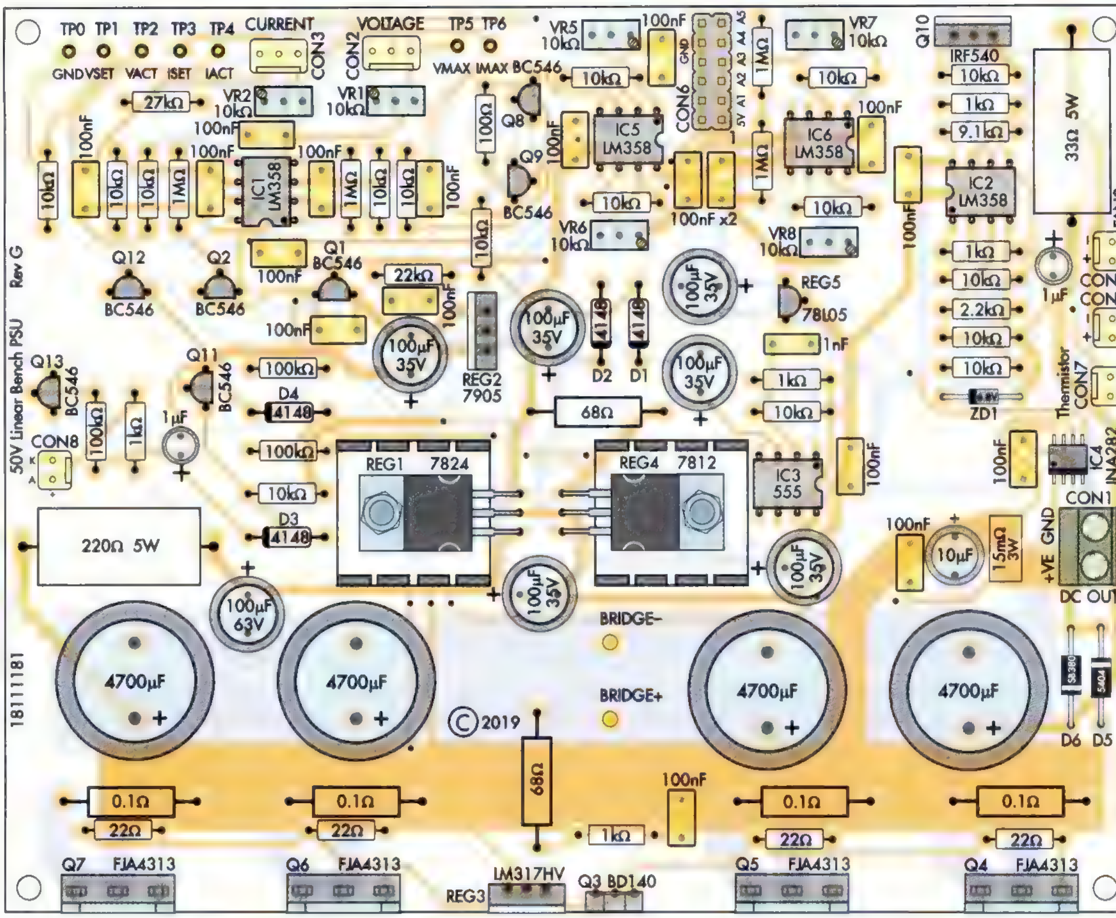


Fig.6: most of the Bench Supply components mount on this control board. Ensure that the diodes, transistors, ICs and electrolytic capacitors are fitted with the correct orientations as shown. It's also a good idea to check carefully that the different value resistors and capacitors go in the right places. Note that one of the 100µF electros is rated at 63V (below and to the right of the 220Ω 5W resistor) where all others are 35V. Fit the four 4700µF capacitors last, after the power devices (that mount on the heatsink along with the bridge rectifier) have been soldered in place.

coded bands, these can be hard to distinguish, so it's best to check each with a multimeter set to measure ohms before soldering them in place.

Next, fit the six 1W resistors and the two larger diodes (D5 & D6), again ensuring their cathode stripes are facing in the directions shown in Fig.6. Watch out as they are orientated differently.

The next job is to fit DIP ICs IC1-IC3, IC5 and IC6. These are all LM358 op amps except for IC3, which is a 555 timer.

You don't need to use sockets; in fact, it's better to solder these all directly to the PCB. But make sure that in each case, the pin 1 dot/notch is facing as shown in the overlay diagram and the IC is pushed down fully onto the board before soldering all of its pins.

The next components to mount are the MKT and ceramic capacitors. The MKT capacitors are mostly 100nF in value, although one is 1nF so don't get them mixed up. The location for each capacitor is shown in Fig.6.

You can now solder the seven BC546 transistors in place, along with REG5. The transistors and regulator look similar so don't get them mixed up. You may need to bend their leads out with small pliers to fit the PCB pad patterns.

Next, mount DIL pin header CON6, followed by the trimpots. Orientate them so that the adjustment screws are positioned as shown in the overlay diagram. They are all the same value.

Follow with the two 5W resistors, which can be installed slightly above the PCB surface to improve convective cooling, although this is not critical.

Note that, as explained last month, you may need to change the value of the 33Ω 5W resistor if you're using different fans from the ones specified (which we don't recommend!).

Now fit the terminal block (CON1), with its wire entry holes facing the edge of the board, and polarised headers CON2-CON5, CON7 and CON8. The polarised headers should be mounted with the orientations shown in Fig.6.

Onboard regulators

REG1 (7824) and REG4 (7812) both need flag heatsinks as REG1 drops around 20V and REG2 drops 8V. Both are mounted identically but rotated 180° relative to each other.

Start by lining up the component with its footprint to determine where the leads need to be bent down by 90°. Having bent the leads, check that the tab mounting hole lines up with them inserted. If not, adjust the bend.

When you are happy with this, smear a small amount of thermal compound on the back of the regulator and mount it by sandwiching the flag heatsink between the regulator and the PCB.

Fasten with a 6mm machine screw from the bottom and a nut on the top of the tab. Ensure the nut is tight but be careful not to twist the regulator and its leads.

Ensure the regulator and heatsink are square within their footprints and not touching any other components before soldering and trimming their leads.

You can fit most of the electrolytic capacitors next; all but the four large 4700µF units. They are polarised; in each case, the longer (positive) lead must be soldered to the pad marked with a "+" on the PCB. The cans have stripes on the opposite (negative) side.

Follow with the two remaining onboard TO-220 components, REG2 and Q10. These do not need heatsinks as their dissipation is quite low. They can be fitted vertically, but make sure that

Compare the PCB layout opposite with this shot of the completed board, albeit with its transistors (and bridge) already fixed to the heatsink

their tabs are facing as shown in Fig.6.

Connecting the off-board components

Presuming that you are using the Five-way Panel Meter module for display, you will need to build that separately (see the article starting on page 90). If you're using individual panel meters, we'll leave that part of the construction up to you. Most of the work is in cutting holes for them in the front panel and wiring them up.

Voltage and current adjustment potentiometers VR3 and VR4 mount on the front panel and connect to the PCB using flying leads and polarised plugs. This prevents them from being accidentally connected backwards if the unit is later disassembled.

Separate a 150mm length of 10-way ribbon cable into two three-way pieces and three two-way pieces. Trim the two three-way pieces to around 10cm each, separate the wires at each end, strip them and solder one end of each to the leads of VR3 and VR4. You may wish to protect the solder joins with short pieces of small diameter heatshrink tubing.

Now crimp the polarised plug pins onto the other ends of the wire. If you don't have the correct tool, it may be easier to solder the wires, although the tabs of the pins will still need to be bent over to fit into the housing.

You can crimp them using small pliers in a pinch (no pun intended), but it's a bit tricky. These will plug into CON2 and CON3.

The square pads of CON2 and CON3 are connected to ground, so should go to the ends of the potentiometer tracks which have a low resistance to the wipers with the pots fully anti-clockwise. The middle connections of CON2 and CON3 go to the wipers, and the third pin goes to the other end of the tracks.

You can check this by verifying that, with the pot cables plugged into the board, the middle pins have a low resistance to ground (TP0) when the relevant knob is wound fully anticlockwise. If this is not the case, you may have the outside leads reversed.

LED1 is also attached using flying leads and mounted off the PCB, via CON8. Solder a length of the two-way ribbon cable to the pins for a matching polarised plug, then solder the other ends of the wire to the LED. The longer lead of the LED must be soldered to the wire that goes to the pad on CON8 marked with a plus sign.

If using a pre-wired panel mount LED, simply crimp or solder the wires to the plug pins and push them into the housing. If you have a bare LED, you should heatshrink the wires to insulate and protect them, and use a bezel for mounting.

If your fans are not already terminated with 2.54mm-pitch headers, attach a keyed plug as for the LED. Note that the positive lead for both fans (ordinarily red) goes to the pin closest to output connector CON1.

A similar header is used to connect the NTC thermistor for monitoring the heatsink temperature. It is not polarised like the other components, but you can still fit the same style plug to connect to the locking header on the PCB, so do that now.

The bridge rectifier (BR1) is mounted on the heatsink and connected to the transformer and PCB via four stout (10A-rated) wires. Cut two wires around 7cm long and crimp or solder spade terminals to one end of each. Protect the outside of the spade using heatshrink tubing insulation.

Solder the other end of the wires to the PCB. The red wire should go to the terminal marked BRIDGE+ (and the bridge rectifier terminal with a plus) and the black wire to the terminal marked BRIDGE- (and the diagonally opposite bridge rectifier terminal).

Initial testing

Now detach all the external components except for the two potentiometers, VR3 and VR4, and the NTC thermistor. This will allow you to do some basic checks.

Before powering the board up, double-check the construction so far, making sure that all the onboard components have been fitted, with the correct polarity. Check also that

We've "opened out" this otherwise completed Supply to give you a better idea of what goes where and with what. Note the Presspahn insulation (fawn colour) which isolates the bitey bits from the rest of the circutiry – just in case,.

the solder joints all have good fillets, do not look dry and that there are no shorts between solder joints on the underside of the board.

The initial tests are only made at low power, but there is still enough energy present to damage components if something has been installed incorrectly. There is the possibility of components becoming very hot if a fault occurs, hence the initial low-power tests which should hopefully find any problems before delivering enough energy to do any damage.

Note that there can be 70V differential voltage between various parts of the circuit when it is powered on. This is enough to give a shock. Make sure the PCB is mounted on insulated tapped spacers and there is nothing underneath the board which might cause a short circuit (eg, do not place it on a metal surface!).

Before powering up the unit, wind all the trimpots and variable resistors to their minimum positions. This includes the six trimpots on the PCB and the two externally mounted adjustment potentiometers.

The best way to do the initial tests is with a variable DC supply fed into the BRIDGE+ and BRIDGE- leads with the appropriate polarity. You will need around 40V to ensure that REG1 is delivering the full 24V at its output.

If you don't have a 40V DC supply, you can feed 27-39V DC directly into REG1's input (with the positive lead clipped to the right-hand lead of the 220Ω 5W resistor). Or you can feed 24V into REG1's output, via the left-hand lead of the 68Ω 1W resistor. But in the latter case, any faults in REG1 itself may not show up.

It would be ideal if you can monitor the current drawn by the circuit; if your supply lacks an ammeter, you can monitor the voltage across the 220Ω 5W resistor, assuming that you are not bypassing this due to a lower test supply voltage.

Power up the circuit and check the current draw. It should be around 60mA, which corresponds to 13.2V across the 220Ω resistor. If there is a severe fault, then you will see a much higher voltage across this resistor and it could get very hot. In that case, shut off power as soon as possible and check for faults. Any more than 20V across this resistor means that something is wrong.

Assuming the current draw is OK, you can now check the various voltage rails for correctness. Connect the negative multimeter probe to ground via TP0 and check the voltages with the positive probe. The 24V rail can be measured at the left end of the 68Ω resistor (assuming you aren't feeding power in there, as there would be little point in checking it then).

You should get a reading close to 24V, although it may be lower if your test supply does not have a high enough output. As long as it is above 18V, the remaining voltage rails should still be correct.

But you will not be able to complete the calibration until 24V is available from REG1, nor can you accurately calibrate the device if feeding power into the 24V rail.

The 12V rail can be measured at pin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PARTS LIST – LINEAR 45V 8A BENCH POWER SUPPLY

1 double-sided PCB coded 18111181, 150 x 120mm
1 vented metal instrument case [Jaycar HB5556]
{ 1 Five-way Panel Meter module (see article starting on page 90)
WITH 1 acrylic bezel [Silicon Chip Online Shop Cat SC5167]
OR 1 set of separate 5V panel meters and suitable mounting hardware
1 acrylic spacer for heatsink [Silicon Chip Online Shop Cat SC5168]
1 40V 500VA toroidal transformer [element14 2817710]
1 35A 400V bridge rectifier (BR1) [Jaycar ZR1324, Altronics Z0091]
1 IEC mains input socket with fuse and switch [Jaycar PP4003, Altronics P8340A]
1 150 x 75 x 46mm diecast finned heatsink [Jaycar HH8555]
2 24V DC 80mm high-flow fans [Digi-key P122256]
2 80mm fan filter/guard [Jaycar YX2552]
2 TO-220 flag heatsinks, 6073B type (for REG1 & REG4) [Jaycar HH8502, Altronics H0630]
1 16V DC/230V AC 16A SPST or DPDT panel-mount toggle switch [Jaycar ST0581/ST0585]
1 208 x 225mm sheet of Presspahn or Elephantide [Jaycar HG9985]
2 TO-220 insulated mounting kits (for Q3 & REG3) [Jaycar HP1176]
1 2-way terminal block, 5mm pitch (CON1) [Jaycar HM3172, Altronics P2032B]
2 3-way polarised headers (CON2,CON3) [Jaycar HM3413, Altronics P5493]
2 3-way polarised plugs (for VR3 & VR4) [Jaycar HM3403, Altronics P5473 + P5470A)
4 2-way polarised headers (CON4,CON5,CON7,CON8) [Jaycar HM3412, Altronics P5492]
4 2-way polarised plugs (for LED1, thermistor & fans) [Jaycar HM3402, Altronics P5472 + P5470A]
1 6x2-pin header (CON6) [Jaycar HM3250, Altronics P5410]
2 12-pin IDC headers (to connect CON6 to Panel Meter) [Digi-Key 2057-FCS-12-SG-ND]
1 10kΩ stud-mount or lug-mount NTC thermistor [Digi-key 495-2138, Altronics R4112]
11 6.3mm spade crimp connectors (for BR1 and mains socket)
1 red chassis-mount banana socket/binding post
1 black chassis-mount banana socket/binding post
1 green chassis-mount banana socket/binding post
1 6A fast-blow M205 fuse (F1)
2 knobs (to suit VR3 and VR4)
4 instrument case feet and associated mounting hardware

Wire, cable etc
1 1m length of 3-core 10A mains flex
1 1m length of 12-way ribbon cable (to connect CON6 to the Panel Meter module and to connect VR2, VR3, LED1 and the thermistor)
1 1m length of 10A-rated red wire (for BR1 and output terminals)
1 1m length of 10A-rated black wire (for BR1 and output terminals)
1 small tube of thermal paste
various lengths of 3mm and 6mm diameter heatshrink tubing
pack of small (2mm) cable ties
pack of self-adhesive wire clips

Fasteners
8 M3 x 32mm machine screws (for mounting fans)
1 M3 x 15-16mm machine screw and flat washer (for mounting BR1)
5 M3 x 12mm machine screws (for rear panel Earth and mounting Panel Meter)
13 M3 x 9-10mm machine screws (for mounting fans and Q3-Q7)
18 M3 x 6mm machine screws (for panel Earths, PCB mounting, REG1, REG3 & REG4)
4 M3 x 10mm Nylon machine screws (for mounting heatsink)
8 M3 x 15mm tapped Nylon spacers (for mounting fans)
4 M3 x 9mm tapped Nylon spacers (for mounting PCB)
13 6.3mm spade crimp connectors (for BR1, the mains socket and output switch)
6 M3 crinkle or star washers (for panel Earths)
16 M3 hex nuts (for panel Earths, REG3, REG4 and mounting Panel Meter)
12 crimp eyelet lugs, 3mm inner diameter (for panel and output Earths)

Semiconductors
4 LM358 op amp ICs, DIP-8 (IC1, IC2, IC5, IC6)
1 555 timer IC, DIP-8 (IC3)
1 INA282 shunt monitor IC, SOIC-8 (IC4) [Digikey 296-27820-1]
1 7824 24V linear regulator, TO-220 (REG1)
1 7905 5V linear regulator, TO-220 (REG2)
1 LM317HV high-voltage adjustable regulator, TO-220 (REG3) [Digikey LM317HVT/NOPB]
1 7812 12V linear regulator, TO-220 (REG4)
1 78L05 5V linear regulator, TO-92 (REG5)
7 BC546 NPN transistors, TO-92 (Q1,Q2,Q8,Q9,Q11-Q13)
1 BD140 PNP transistor, TO-126 (Q3)
4 FJA4314 NPN power transistors, TO-3P (Q4-Q7) [Silicon Chip Online Shop Cat SC4096]
1 IRF540N N-channel Mosfet, TO-220 (Q10)
1 5mm red LED with bezel (LED1) [Jaycar SL2610, Altronics Z0220]
1 6.8V 1W zener diode (1N4736 or equivalent; ZD1)
4 1N4148 signal diodes (D1-D4)
1 1N5404 400V 3A diode (D5)
1 SB380 80V 3A schottky diode (D6)

Capacitors
4 4700μF 63V electrolytic [Altronics R5228]
1 100μF 63V electrolytic
6 100μF 35V electrolytic
1 10μF 63V electrolytic
2 1μF 50V multi-layer ceramic
18 100nF MKT
1 1nF MKT

Resistors (all 1/2W 1% metal film unless otherwise stated)

4 1MΩ	3 100kΩ	1 27kΩ	1 22kΩ	16 10kΩ
1 9.1kΩ	1 2.2kΩ	5 1kΩ	1 220Ω@	1 100Ω
2 68Ω#	1 33Ω@	4 22Ω		

4 0.1Ω# [Digi-Key 0.1GCCT-ND, Mouser 603-KNP1WSJR-52-0R1]
1 0.015Ω 2W or 3W, SMD 6432/2512 size [Digikey YAG2165CT, Mouser 603-PE252FKE7W0R015L]
6 10kΩ vertical multi-turn trimpots (VR1,VR2,VR5-VR8)
2 10kΩ linear 24mm potentiometers (VR3,VR4)
 # 1W 5%   @ 5W 10%

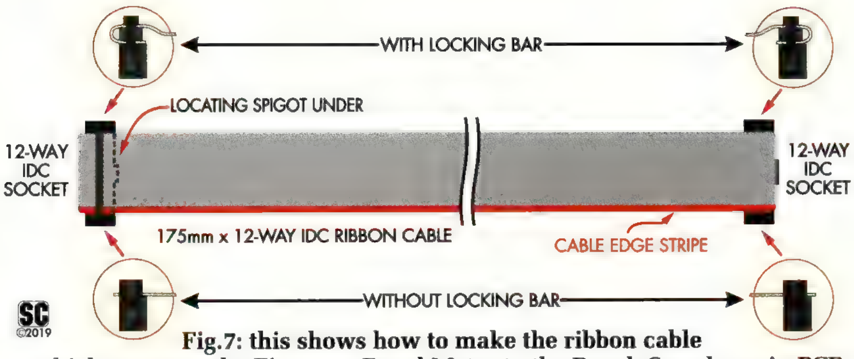

Fig.7: this shows how to make the ribbon cable which connects the Five-way Panel Meter to the Bench Supply main PCB. Whether your cable looks like the pictures inside the upper or lower circles depends on the style of IDC connector that you are using.

4 or 8 of IC3. If the 12V rail is correct, then the negative rail generator should be working, and the tab of REG2 should have around -9V on it. The output of REG2 is connected to pin 4 on IC1, IC5 and IC6 and these should all be close to -5V.

Finally, the output of the +5V rail can be found at pin 1 of CON6 (marked "5V"). The outputs on CON6 marked A1-A4 correspond to the signals for the external panel meters. They should all read 0V if trimpots VR3 & VR4 are fully clockwise.

Pin A5 on CON6 should read around 3-4V if the thermistor is working correctly, but it may be a bit lower at high ambient temperatures.

If this is correct and you have built the Five-way Panel Meter, it can now be connected to CON6 to allow it to be calibrated (see the section on making the ribbon cable below, if you haven't already done so).

All the readings, apart from the temperature, will be incorrect until calibration is complete.

If you are using individual panel meters, they can be connected now. Due to the limited current available from REG5, separate digital panel meters may need a separate 5V supply.

Initial calibration

Now check the voltages TP5 and TP6. TP5 should be at around 12V if VR1 has been wound to its minimum. Once you've verified that, adjust VR1 until TP5 measures 15.6V.

This sets up VR3 to provide 50V at the output when fully clockwise. This depends a little on the exact properties of trimpot VR3 itself, but this setting can be fine-tuned when construction is complete and you can measure the actual output voltage to full scale.

Similarly, adjust VR2 to get 6V at TP6, corresponding to approximately 8A at the output. This too can be fine-tuned later. If you wish to set a more conservative maximum current limit, you can adjust VR2 for a lower voltage at TP6.

At this stage, TP1 and TP3 should all be showing very close to 0V. If not, adjust VR3 and VR4 respectively so that this is the case. This ensures a minimum output voltage when the unit is fully powered up later.

TP2 and TP4 should also be near (or even below) 0V. This shows that the output voltage and current are both zero. You should not proceed unless this is the case, as there should be no output with REG3 absent. If you get positive readings here, check around IC1 and IC4 for circuit problems before proceeding with any high-power tests.

We will need to adjust VR4-VR7 later; this is not possible until the Supply is fully assembled.

Other checks

If you have a frequency meter or oscilloscope, you can check the two oscillators. Their exact frequency is not critical, but significant variations can indicate other problems.

The oscillator for the negative rail generator is at pin 3 of IC3 and should measure around 60kHz. You should also check the duty cycle if possible; it should be close to 50% for maximum efficiency. If the duty cycle is wrong, and the negative rail is not reaching -5V, the values of the components around IC3 may be incorrect.

The frequency of the fan PWM circuit can be measured at pin 1 of IC2. This should be around 280Hz, with a 50% duty cycle. Pin 1 delivers a square wave while pin 2 can be probed to check the 'triangular' waveform if you have a 'scope. With the thermistor near 25°C, the fan PWM output at pin 7 of IC2 should be off, so a voltmeter will read 0V.

If the thermistor is warmed up (such as by being held in a warm hand), the average voltage at pin 7 should rise to at least 3V, representing a 12V PWM signal with a duty cycle of around 25%. This indicates that the thermistor circuit is working as expected.

Mounting the power devices

Once you are happy with the results of the tests outlined above, the power components can be added to the board. Disconnect the power and allow the capacitors to discharge, which may take a minute or so.

The components in this area connect via thick tracks and may need more heat than the earlier components to solder.

Re-check now that the heatsink is free of swarf and metal dust, as these can puncture the transistor insulating pads and cause a short circuit. The face of the heatsink should be smooth. A light sanding with fine sandpaper will help to flatten any raised areas.

First, mount transistors Q3-Q7 and REG3 loosely to the heatsink. Use a 6mm M3 machine screw, insulating bush and insulating washer for REG3. The mounting for Q3 is the same as REG3 except that you'll need a longer, 10mm screw. Mount the four large transistors using 10mm-long M3 machine screws, with a thin smear of thermal paste over the side of the devices which touch the heatsink.

While Q3 is in a TO-126 package, a TO-220 insulating mounting kit will work fine with some careful trimming. Note that Q3 has its plastic face mounted against the heatsink, so the washer is more to ensure good contact than it is for insulation.

Check for continuity between the heatsink and leads of Q3 and REG3; there should be no continuity on any of the leads. You will need to probe the non-anodised face of the heatsink. If there is, remove that part, check the insulation and reattach. You must do this before soldering or fitting the PCB, as Q3's emitter is effectively connected to the heatsink via the collectors of Q4-Q7.

Now position the 3mm acrylic spacer next to the PCB, with the latter sitting on its 9mm tapped spacers. Line up the power device leads with the PCB pads and drop them into place, with the heatsink resting on the acrylic spacer.

Check the device mounting heights

and adjust if necessary. Then solder one lead at each end of each device. You can then carefully flip the whole assembly over and solder all the pins thoroughly, with the PCB resting on something to prevent it sagging under its own weight. When finished, trim the leads short.

Tighten up all the screws holding the devices to the heatsink and check that they are firmly attached, as once the large electrolytic capacitors are fitted, access will be limited. You might also like to re-check that REG3 and Q3 are still insulated from the heatsink.

Next, smear the face of BR1 with thermal paste and attach it to the heatsink using a 16mm-long M3 machine screw and flat washer. Install it with the positive terminal at the bottom. This means that the wires do not need to cross over to reach the PCB terminals. The bridge has a bevel to identify the positive terminal, and will typically also be printed with a "+" symbol on the side.

Connect the BRIDGE+ and BRIDGE- terminals to the bridge rectifier by pushing the spade connectors onto its tabs.

The final components to fit are the four 4700µF 63V capacitors mounted directly in front of the output transistors. Their negative stripes must face towards the front edge of the PCB. Solder them in place and trim the leads to complete the component assembly.

Now is a good time to attach the thermistor to the heatsink. If using the stud-mount type, thread it into its hole on the heatsink. If using the lug type, attach it with a machine screw and shakeproof washer. Mount it on the flat side of the heatsink so that it is not directly cooled by airflow from the fans.

Check the thermistor leads for continuity against the heatsink; there should be none. If there is, check the mounting and re-insulate as necessary.

IDC ribbon cable assembly

Now is a good time to make up the IDC cable that will connect the Five-way Panel Meter to the control board (assuming you're using that meter and not some other arrangement). Cut a 175mm length of 12-way ribbon cable and attach the IDC sockets at each end with the same orientation. So with the cable stretched out flat, the two polarising tabs on the IDC connectors should face the same way.

If you can't get 12-way ribbon cable, take some wider ribbon cable, cut between the 12th and 13th wires and then gently pull the two sections apart. They should separate cleanly.

See Fig.7 for details on how to make this cable. Usually, IDC connectors are supplied as three pieces: the main part of the connector, with holes to mate with the pin header on the bottom and blades to slice through the cable insulation on the top; a plastic clamp which is pressed down on the top of the cable to force it into the blades, and a locking bar which provides strain relief and holds it all together.

The way the cable is fed through these three-piece IDC connectors is shown at the top of Fig.7. But the 12-way IDC sockets we purchased only consisted of two pieces, with the clamp and locking bar integrated and no provision for cable strain relief. This arrangement is shown in the lower two circles. Make your cables to match one or the other, depending on the style of IDC sockets that you have.

It's essential to use sufficient clamping force to ensure that the blades properly pierce the cable insulation and make contact with the copper strands within, without pressing so hard that you break the plastic.

You can do this in a vice; however, a proper IDC crimping tool generally makes the job easier (eg, Altronics Cat T1540).

More testing

Now that you've finished assembling the control board, assuming you have a suitably safe source of AC or DC power, you can do some more testing.

Plug in the Five-way Panel Meter, VR3, VR4, thermistor and LED and then apply power to the two unconnected terminals of BR1. You can use 24-40V AC or 30-58V DC.

If you can limit the current to a few hundred milliamps, that's a good idea, but note that this will mean that it takes some time for the main capacitor bank to charge, and it will draw the maximum current as it does so.

Once the Supply is powered up, check that the Panel Meter powers up too. You may need to tweak the brightness and contrast if these have not been set.

The voltages and currents should all read zero as VR5, VR6, VR7 and VR8 should have all been set to their minimum and have not been calibrated. The temperature shown on the Panel Meter should be around ambient if the thermistor is wired up correctly.

Assuming that it checks out OK, power it off; it's time to start preparing the case.

We'll have the full details on the final assembly and testing in part 3, next month.

We'll cover the final assembly of the supply in the third and final part of this project next month.

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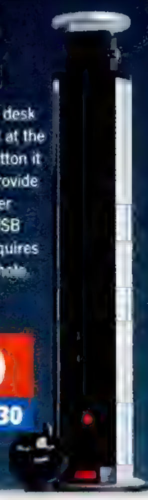

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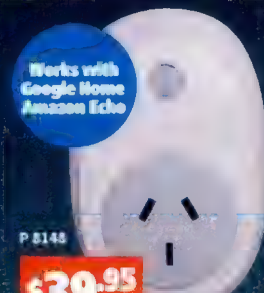

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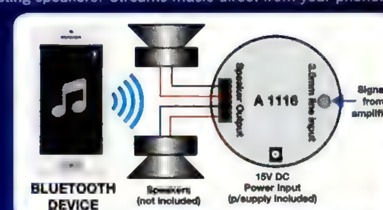

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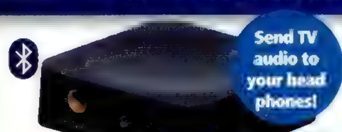

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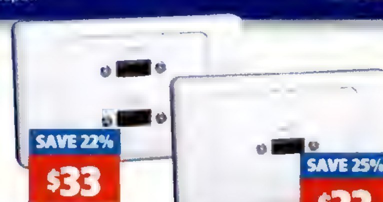

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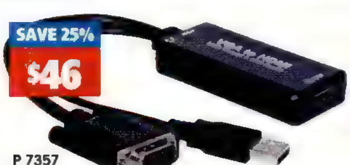

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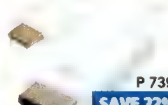

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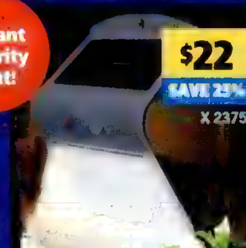

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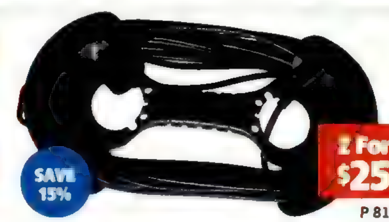

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CIRCUIT NOTEBOOK

Interesting circuit ideas which we have checked but not built and tested. Contributions will be paid for at standard rates. All submissions should include full name, address & phone number.

Simple digital sinewave generator

I recently designed a circuit to change one's voice to sound like the Daleks and Cybermen from the science fiction TV show, Doctor Who.

To do this, I used a balanced modulator IC fed with amplified voice as the carrier and a sinewave oscillator as the modulator. To make it sound realistic, I used the original BBC frequencies for the oscillator.

The hard part was making an amplitude-stable low distortion sinewave oscillator with a frequency that could be varied from 30-200Hz by changing one resistor value. This is the circuit I came up with.

The DC voltage on the wiper of the frequency control potentiometer (VR1) is filtered by a 100nF capacitor and then read by the internal analog-to-digital converter (ADC) of the PIC16F88 microcontroller (IC1).

IC1 generates digital sinewave values at its 8-pin RB output port, and the ADC reading determines how long it pauses between each step and therefore, the sinewave frequency.

A 32-point lookup table provides the instantaneous value of a sinewave at each point at 11.25° intervals throughout the 360° cycle (ie, 360° ÷ 32).

The digital value translates into eight digital levels of either 0V or 5V at each of the eight RB port output pins. These are translated into a proportional analog voltage by the R-2R network, which is contained within a single device: a Bourns 4310R-R2R-103LF resistor network.

The resulting voltage is buffered by op amp IC2a, and its output is then fed into a second-order low-pass filter built around IC2b, which has a -3dB point of 402Hz. This removes most of the steps and harmonics from the sinewave.

If you analyse the stepped waveform at output pin 1 of IC2a, you will find that there is very little second and third harmonic distortion present, which is why the roll-off frequency is set so high.

The maximum sinewave frequency that can be produced is determined by the shortest time that the microcontroller can be paused. If this time is t, then the maximum frequency is 1 ÷ 32t.

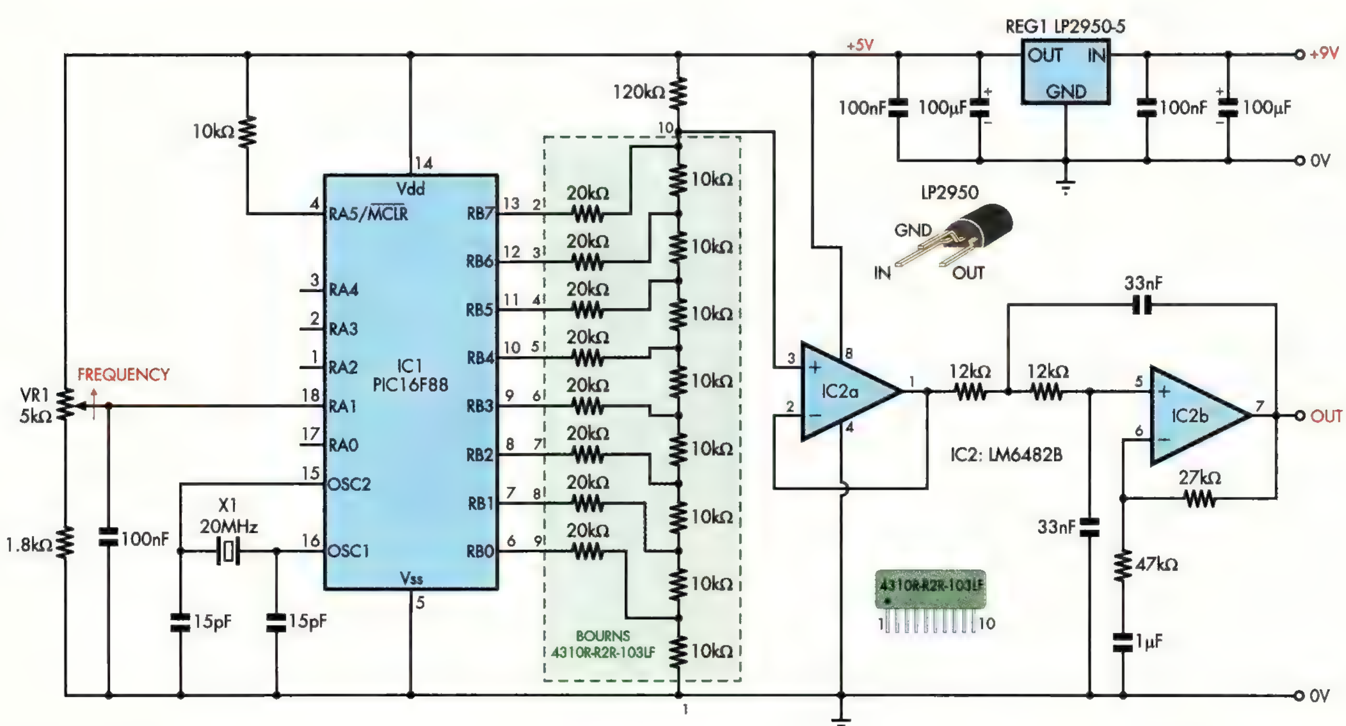
The rest of the circuit is a simple linear regulator arrangement, to provide a stable 5V supply for IC1 and IC2.

The PICBASIC source code (Osc.BAS) and HEX file (Osc.HEX) to load into IC1 are available for download from the Silicon Chip website.

Les Kerr,
Ashby, NSW. ($75)

Editor's note: this could be used in combination with "Voice modulator for sound effects" Circuit Notebook entry from the August 2019 issue (siliconchip.com.au/Article/11777); we published an erratum for that item in the October issue.

The Bourns resistor array is available from Digi-key, Mouser and element14. In a pinch you could use ±1% resistors, potentially with slightly degraded performance.



Shunt regulator for wind turbines

Wind turbines need to be protected against excessive rotational speeds. Without such protection, a wind turbine may experience undue stresses in its moving parts, such as blades and bearings, during periods of high winds. These stresses may lead to premature failure of the turbine.

Shunt regulators are commonly used to protect the wind turbine. A controller of this kind works by automatically applying a load, usually in the form of one or more resistors (collectively referred to as a dump load) to a wind turbine.

The dump load exerts a braking force on the wind turbine to maintain the speed of the turbine within safe limits.

The circuit described here has been designed for use with wind turbine generators rated up to 24V nominal output and 2kW power capacity.

Its supply terminals can be connected directly to positive and negative DC output terminals of a wind turbine. Turbines with three-phase AC output terminals may be connected indirectly via a three-phase bridge rectifier.

The load dump resistor should have a power rating at least as high as the power generation capability of the turbine.

IC1 is a TL594 switchmode controller IC which is functionally identical to, and pin-compatible with, the industry-standard LM494. The main difference is that the TL595 is recommended for operation at temperatures below 0°C, whereas the LM494 is not.

Internally, IC1 comprises a pair of comparators, an oscillator and associated logic circuitry. The latter is connected to an output driver stage which can be programmed for either push-pull or, as in this case, single-ended operation.

The comparators have positive inputs (pins 1 and 16) and negative inputs (pins 2 and 15), as well as a common output connection at pin 3. Only one comparator is required in this application; the two comparators are connected in parallel, to act as a single comparator.

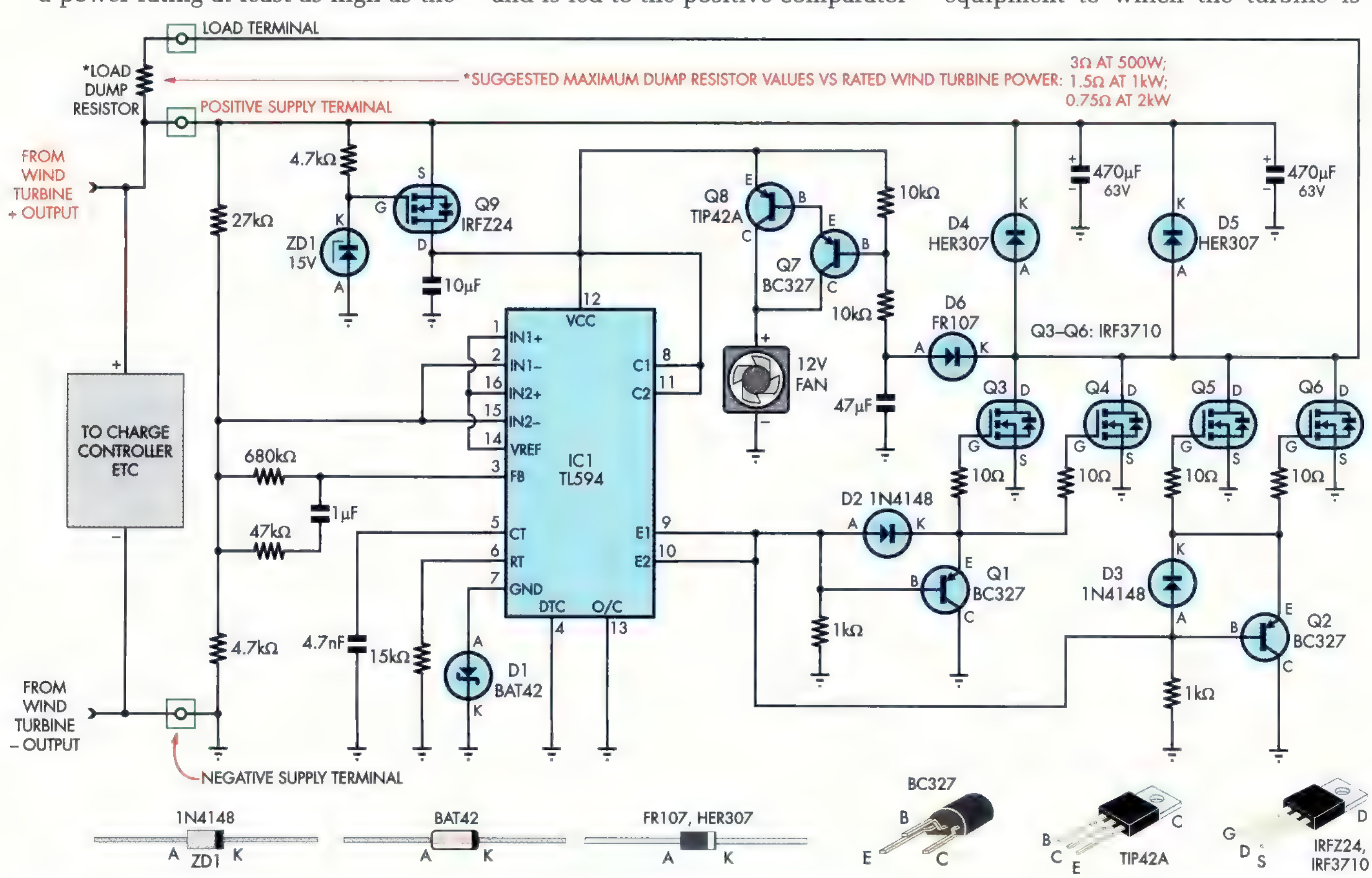
The negative comparator inputs are connected to the junction of a voltage divider across the positive and negative supply terminals. This voltage is compared with a 5V reference voltage which comes from the V_{REF} pin (pin 14) and is fed to the positive comparator inputs. An RC network from the comparator output at pin 3 to the inverting input provides a small amount of hysteresis.

The result is two pulse-width modulated (PWM) signals at output pins 9 and 10, which have duty cycles proportional to the supply voltage. These signals drive the gates of Mosfets Q3-Q6 via diodes D2, D3 and four 10Ω resistors.

Transistors Q1 and Q2 serve to speed up the switch-off, despite the relatively high value of the 1kΩ pull-down resistors.

The negative supply at pin 7 of IC1 is connected to ground via schottky diode D1. This provides a small negative bias voltage (around 400mV) at control pin 4 relative to pin 7, thereby extending the duty cycle range beyond the normal 80% obtainable with the TL594. The duty cycle is extended from a minimum of zero (when the supply voltage is less than the 37V threshold) to a maximum of 100% at higher voltages.

The exact threshold voltage is not critical. Ideally, it should be slightly above the normal operating voltage range, but well within the safe operating range, of both the turbine and equipment to which the turbine is



to be connected. For example, if the normal operating range is 20-36V and the safe operating range is 0-45V, then a threshold voltage of about 37V is a reasonable choice.

The threshold voltage can easily be changed by altering the values of the divider resistors across the supply terminals, connecting to pins 2 and 15 of IC1.

This circuit includes provision for driving a small fan to cool the Mosfets. This part of the circuit comprises PNP transistors Q7 and Q8 in a Darlington configuration, together with diode D6 and an RC network.

When the Mosfets are entirely off, the fan is not required. The 47µF capacitor charges up to V_{CC} via the two 10kΩ resistors, so Q7 and Q8 remain off. But if the Mosfets are pulsing on while driving the dump load, the capacitor discharges via D6, causing transistors Q7 and Q8 to turn on, which in turn causes the fan to run.

Mosfet Q9, zener diode ZD1 and the 4.7kΩ resistor protect the circuit from reversed supply polarity.

When the supply polarity is correct, Q9's internal diode is forward-biased and its gate is pulled positive relative to its source, so that diode is shorted out, minimising the voltage drop across the device. ZD1 prevents its maximum gate-source voltage from being exceeded.

But if the supply polarity is reversed, its internal diode is reverse-biased and its gate is pulled below its source, so Q9 does not conduct.

Herman Nacinovich,
Gulgong, NSW. ($100)

Digital soldering iron stepping timer

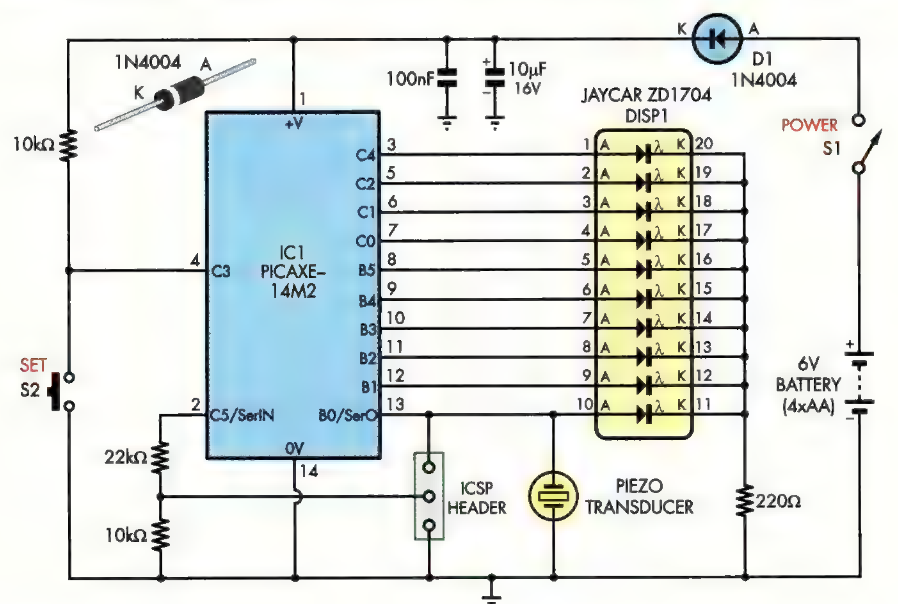
It's easy to accidentally leave a soldering iron on for long periods of time. This is detrimental to the iron in general and the tip in particular, and it wastes power too. This circuit reminds you that your soldering iron is still switched by waiting for a pre-set time and then sound a series of beeps. This timer does not automatically turn the soldering iron off; you must operate the switch.

This soldering iron timer should be placed on your workbench near to your soldering iron as this makes it easy to turn on the timer each time you turn on your soldering iron. Then after some time has passed, a series of beeps will alert you that your soldering iron is still running. You can then press pushbutton S2 to reset the timer, or switch off the soldering iron and the timer unit.

The circuit is based on a PICAXE-14M2 microcontroller (IC1) and all functions are software controlled. The elapsed time is shown on a 10-LED array (DISP1) which steps slowly from the upper LED to the lower LED over the timing period. This is followed by the lower LED flashing while the piezo transducer emits beeps at six-second intervals until the alarm is reset using S2 or switched off using S1.

You can pre-set a default time of 10 seconds (quick test), 10 minutes, 15 minutes, 20 minutes, 25 minutes, 30 minutes, 35 minutes: 40 minutes, 45 minutes or 50 minutes. To do this, hold S2 while turning on power switch S1 and the LEDs will light in turn to indicate each of the above times. Release S2 to make that time the new default. It is saved in EEPROM, and so is not lost when the power is off.

The LED array (Jaycar ZD1704 or similar) has its anodes driven from 10 output pins of microcontroller IC1. Since only one LED is on at a time, their cathodes can share a common 220Ω current-limiting resistor.



Digital input C3 (pin 4) is used to monitor pushbutton S2. An in-circuit serial programming header is provided, connecting to the serial input (pin 2) and the serial output (pin 13) of the microcontroller to update the firmware.

Power is from a 6V battery pack (eg, four AA cells) via power switch S1 and reverse-polarity protection diode D1. D1 also reduces the battery voltage to below 5.5V, to suit the requirements of microcontroller IC1. You could use a plug pack rather than batteries; a USB phone charger will supply 5V DC. Higher-voltage plugpacks will need a 5V regulator added.

The prototype was built on a single DIP pattern stripboard, but two boards could be used, with one for the microcontroller and one for the LED array. The board assemblies can then be mounted in a suitable Jiffy box along with the battery, power switch and push button.

The beeper is a piezo transducer (Jaycar AB3440 or similar), and the alarm sounds are produced in software. Pushbutton S2 should have tactile or snap-action contacts.

The PICAXE website explains how to use your PC or laptop to program the PICAXE14M2 microcontroller (IC1). You will need a USB cable (P-AXE027 from Wiltronics), a copy of the free program editor and a suitable USB driver (www.picaxe.com/Software/Drivers/AXE027-USB-Cable-Driver/).

Download the PICAXE BASIC program "timer_iron1_14m2.bas" from the SILICON CHIP website, then upload this program to the chip using the USB cable connected to the ICSP header.

Ian Robertson,
Engadine, NSW. ($75)

"The Farmer's Friend" – discrete pump timer

Rural properties that rely on tank water often have an electric pump which is activated by an internal switch. This detects low pressure in the pipes, indicating a demand for water. If the pipe leaks, the pressure will remain low and the pump will run until the tank is empty; a serious loss at any time but disastrous in times of drought.

This circuit is designed to allow intermittent activation of the pump due to normal usage, but if the pump runs continuously for a set period, power to the pump will be cut off until the unit is reset. The circuit might also have other uses.

We have published a few circuits in the past which do a similar job, the most recent being the Cyclic Pump Timer from September 2016 (siliconchip.com.au/Article/10130) and a 12V DC version of the same circuit in the July 2016 issue (siliconchip.com.au/Article/10727).

But both of those designs are based around a PIC microcontroller, while this one uses mostly discrete parts, plus a dual op amp and dual timer IC.

When the pump switches on and starts drawing current, this is sensed by a toroidal transformer (T2) consisting of a two-turn primary, with the secondary being the windings of a 470µH toroidal inductor (Jaycar Cat LF1278).

The voltage induced in the secondary is amplified by op amp IC1a, and diodes D5 and D6 rectify its output. A bleeder resistor is included across the smoothing capacitor to ensure rapid decay when the pump switches off.

At pump switch-on, the output of Schmitt trigger inverter IC1b falls rapidly, triggering the first timer in IC2 via a 1nF capacitor to pin 6. That causes its output at pin 5 to go high. When output pin 7 of IC1b goes low, NPN transistor Q1 also switches off, allowing 100µF capacitor C1 to start charging from the 12V supply via the 1kΩ and 10MΩ (R1) resistors.

With these values, after about 17 minutes, the timer will be reset via the voltage at pins 1 & 2, and its output (pin 5) will go low. This triggers the second timer in IC2, which generates a one-second pulse, activating latching relay RLY1 (Jaycar Cat SY4060).

This removes power from high-current relay RLY2, a 30A 12V normally open type (Jaycar Cat SY4040). Thus power to the pump is off until the circuit is reset by pushing S1.

If the pump turns off while capacitor C1 is still charging, transistor Q1 switches back on and discharges the capacitor via diode D1, resetting the time delay; there will initially be some residual charge in the capacitor due to the forward voltage of D1. The voltage at TP1 is low when the pump is on, while TP2 is low when the pump is off.

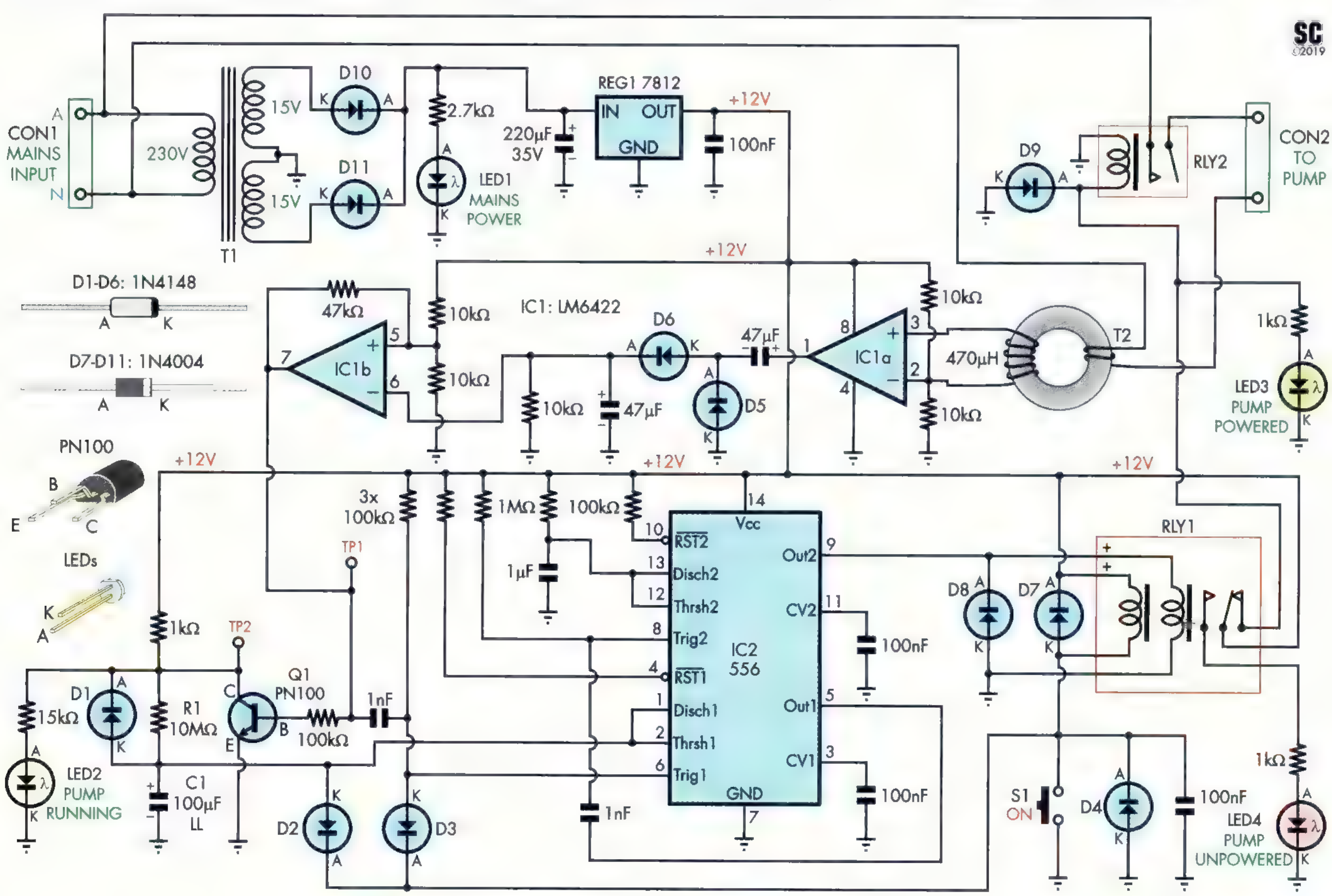
If you remove D1 then pump switch-off could still be triggered even if the pump is cycling on and off, which may occur with smaller leaks, so this could be worthwhile.

Power to the pump can be restored by momentarily pressing S1, which resets the latching relay and restores power to the pump. Pressing S1 discharges capacitor C1 via diode D2 and also triggers the first timer via diode D3, so if the pump is still active, the capacitor will resume charging. Otherwise, it will remain discharged as Q1 will be switched on at the time.

The maximum pump run time in seconds is approximately equal to the product of R1 in megohms and C1 in microfarads. C1 must be a low-leakage type. The very high input impedance of CMOS timer IC2 allows R1 to be increased to 20MΩ, so the delay time could be increased to about 30 minutes.

Note that the primary winding of T2 is made from heavy-gauge mains-rated wire for safety, and the rest of the mains wiring should use the same.

James Goding,
Princes Hill, Vic. ($80)



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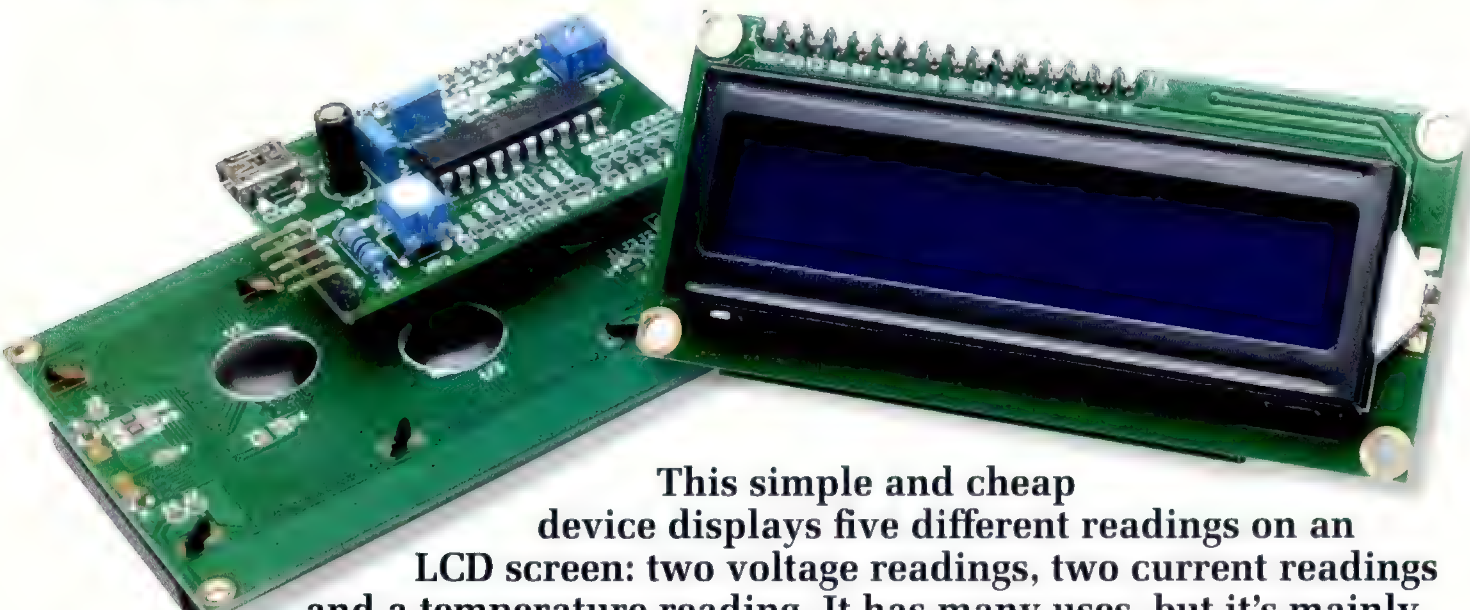
FIVE-WAY LCD PANEL METER AND USB DISPLAY

by Tim Blythman



This simple and cheap device displays five different readings on an LCD screen: two voltage readings, two current readings and a temperature reading. It has many uses, but it's mainly intended to replace multiple panel meters. It can also be used as a small additional text screen for a PC, Raspberry Pi or any other computer with USB.

We came up with this idea while working on the high-current linear power supply design that we started describing last month (part 2 starts on page 68 of this issue).

We needed a way to show several different voltage and current readings, along with heatsink temperature, and it just didn't make sense to use several panel meters for that job.

It's difficult enough to cut a single neat rectangle in the front panel of the instrument case to fit one screen, let alone three or even five. And there would be a lot of extra wiring if we used separate panel meters, plus increased current draw and it could end up pretty expensive.

This one low-cost device using a micro, an LCD screen and not much else makes the whole thing so much easier.

There are two ways to use this board. In the Bench Supply, we're feeding in five analog voltages with a common ground. These voltages are a fraction of the actual measured voltages (ie, the outputs of voltage dividers). The onboard micro samples these voltages and converts the values back to the original scales, then displays on them on the screen.

In the case of the fifth input, which is used for temperature sensing via an NTC thermistor, it also performs the required calculations to deal with the non-linear behaviour of the NTC.

In the other mode, the micro detects when it is plugged into a USB interface and then behaves differently. You send it text over a virtual serial link, which is shown on the display. So you can easily show whatever you want on the 16x2 or larger 20x4 character backlit LCD screen.

More details

Our 45V 8A Linear Bench Supply, mentioned above, has five main parameters to monitor. Those are the desired voltage and current, the actual output voltage and current (which may be lower than the desired values in some cases), plus the heatsink temperature.

It will automatically switch on fans if the heatsink gets hot, and throttle back its output in the worst case if that doesn't help. But it's still handy to have a way to tell how close to the wind you're sailing!

We settled on using a PIC16F1459 microcontroller to monitor and display these voltages. It's a low-cost micro

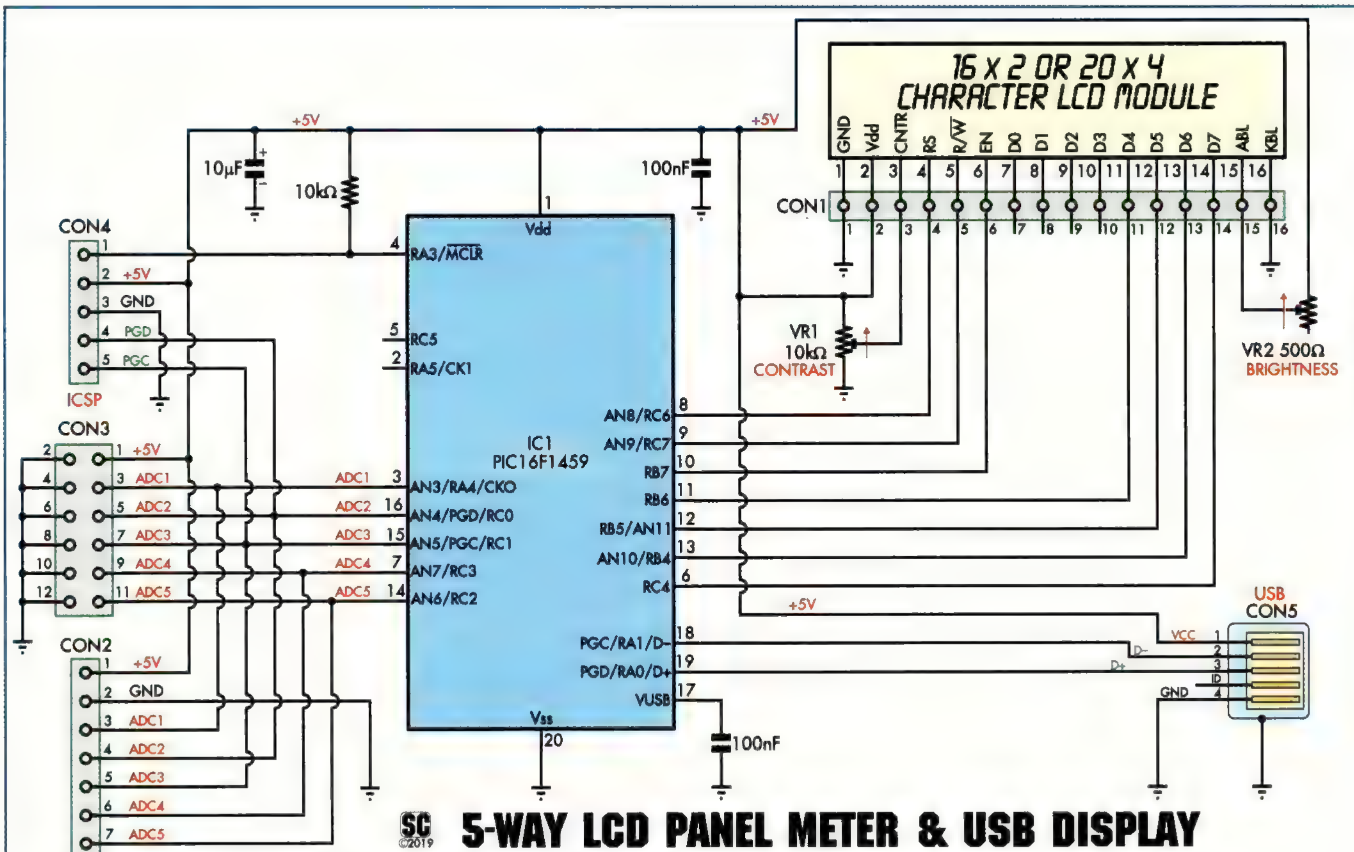


Fig.1: the circuit is quite simple. Microcontroller IC1 uses its internal analog-to-digital converter and 4.096V reference to measure the voltages at the ADC1-ADC5 inputs. It then scales the readings from ADC1-ADC4 and converts the reading from ADC5 to a temperature before updating the LCD connected via CON1. In USB Display mode, it instead receives text from a PC via CON5 and updates the display.

with some nice features. It's similar to the PIC16F1455, but it has more I/O pins, which makes it easier for us to interface with an LCD panel.

Both the 16F1455 and 16F1459 have USB interfaces, making it easy for us to implement the USB mode as a 'bonus' feature.

In this bonus mode, it is effectively a character LCD that can be controlled from your computer. If you want some extra information displayed 24/7 without needing to have a full-size monitor switched on and drawing power the whole time, it's an ideal solution.

It's even small enough to be mounted in a desktop computer's drive bay.

You could use it to display things like CPU load, memory usage, disk space usage, network activity, instant messages, unread e-mails... the list is virtually endless.

You just need to figure out how to get that information and send it to a serial port, and the display does the rest.

Circuit description

The circuit of the Display is shown in Fig.1. The aforementioned PIC16F1459 microcontroller is shown as IC1.

Its 5V power supply comes from either pin headers CON2/CON3, when used in the panel meter role, or CON5, the USB socket. The data pins from the USB socket are connected directly to pins 18 and 19, the dedicated USB data pins of IC1.

In the panel meter role, the five voltages are fed into either SIL header CON2 or DIL header CON3, whichever is more convenient. CON3 has the advantage that an IDC header on a 12-way ribbon cable can plug straight in, and each signal wire will have a ground wire on either side, minimising noise pickup

The five signal lines go straight to analog inputs AN3, AN4, AN5, AN7 and AN6 of IC1 (pins 3, 16, 15, 7 & 14). IC1's internal 10-bit analog-to-digital converter is used to read these 0-4.096V signals and convert them to digital values, with a resolution of 4mV ($4.096V \div 2^{10}$)

The 4.096V reference is within IC1, and we're using this rather than the 5V rail so that variations in the 5V supply do not affect these readings. That means we don't need to be concerned about how well regulated the 5V rail is.

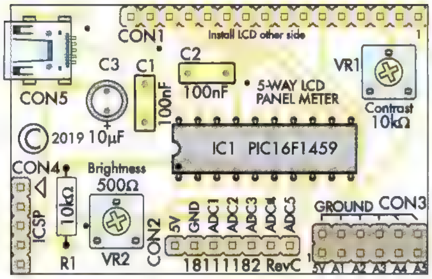
These are scaled in software to the values shown in the spec panel, which are designed to suit our power supply, but these values will be useful for a range of low-voltage DC monitoring tasks.

You simply need to arrange for shunts to monitor currents, and dividers with approximately the right ratios (around 15:1 for voltages) plus trimpots for calibration, to feed the right voltage ranges to the panel.

An HD44780-based character LCD screen is connected via 16-way header CON1. It is driven in four-bit mode, with the RB6, RB5, RB4 and RC4 digital outputs of IC1 (pins 11, 12, 13 & 6) driving LCD data pins DB4-DB7.

We only need four data pins as these LCDs can operate in a four-bit mode, with the D0-D3 I/Os left floating or tied to ground.

Digital outputs RC6, RC7 and RB7 (pins 8-10) of IC1 drive the RS, R/W and EN pins of the LCD, controlling when the data is clocked and whether the LCD should treat it as an internal



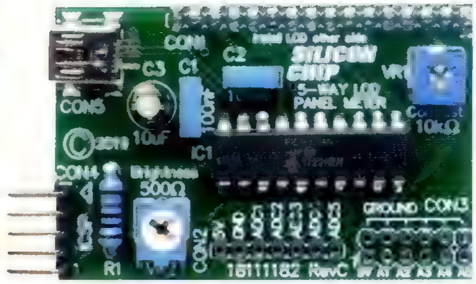


Fig.2: use this PCB overlay diagram and the same-size photo at right as a guide to help build the Panel Meter/USB Display board. The only polarised components are IC1 and the electrolytic capacitor. You can use a socket for IC1 if you want to. CON5 is not required for the panel meter version, while CON2-CON3 are not required for the USB Display version and CON4 is only needed if you plan to program IC1 in-circuit.

command or send it to the display.

Trimpot VR1 adjusts the LCD contrast voltage, while VR2 is wired as a variable resistor in series with the backlight LED, allowing its brightness to be set.

The power supply is simple. There is a 10µF bulk bypass capacitor for the 5V rail, which is the maximum value allowed to meet the USB inrush current specification. IC1 has its own high-frequency 100nF local bypass capacitor.

A 10kΩ resistor pulls up the micro's MCLR pin to 5V to prevent spurious resets, while a 100nF capacitor between pin 17 (VUSB) and ground stabilise its internal USB 3.3V regulator.

The ICSP header, CON4, is provided to allow the PIC to be programmed without having to be removed.

Using it as a panel meter

On power-up, if no USB connection is detected, it will initialise the LCD and show a splash screen. The analog pins are set as inputs, and the analog-to-digital converter (ADC) voltage reference is set to the internal 4.096V fixed reference.

After a second, it begins sampling the analog pins around five times per second. The update interval gives a quick update time, but not so fast that the numbers would blur into each other while changing.

The current and voltage values are converted using fixed internal scaling factors, with the idea being that they have been fine-tuned using external trimpots. The reading from the thermistor is used to find the temperature in a look-up table stored in flash.

The header on CON3 matches the pinout of CON6 on the Bench Supply to allow a direct connection. If the input assignments, scaling ratios etc do not suit your particular application, you can download the source code from our website and change it to better suit your needs.

It is written in the C language. Microchip's MPLAB X IDE software is a free download, and there is a free version of the XC8 compiler (plus a trial mode for the full compiler).

Once you have installed that software, you can open up the project, make some changes to the code and then 'Build' the project to produce a new .hex file for IC1.

We used MPLAB X IDE Version 5.05 and XC8 Version 2.00 and our compiled HEX file was very close to that 8kB limit. We suggest using the same version to avoid going over this limit.

Using it as a USB display

When connected as a USB display, neither CON2 or CON3 are needed as the analog pins are not sampled. On power-up, IC1 enumerates on the connected USB port as a USB-serial device and appears as a serial port to the host.

For example, this would be a COM port on Windows or a TTY device on Linux. The LCD is initialised and blanked and a default set of character graphics are loaded into code points 0-7.

When data is received from the host, (for example, if you were typing into a serial terminal program), it is processed by IC1 and used to update the display. ASCII characters are passed straight on to the LCD, while control characters such as CR (carriage return, ASCII code 13) and LF (line feed, ASCII code 10) move the printing location as expected.

TAB moves to the next screen position which is a multiple of five characters, while FF (form feed, ASCII code 12) moves the cursor to the home position.

Backspace (ASCII code 8) moves back one position, but does not erase anything. A true erasing backspace can be simulated by a backspace, space, backspace sequence consisting of ASCII codes 8, 32 and 8.

Finally, Escape (ASCII code 27) clears the screen, but does not move where the display will print next. Thus a sequence of ESC and FF returns the display to the same state as it is when it first starts up.

The entire display is held in a RAM buffer and sent to the LCD one character at a time, to ensure that the USB peripheral is not left waiting too long for the display to update. This could otherwise happen if the display needs to be cleared and many characters need to change at the same time.

While this might sound slow, the display can still fully update around 10 times per second.

The RAM buffer consists of four rows of 20 characters, as this is the largest display size that the HD44780 controller can manage. Text wraps around at the end of a line and back to the top at the end of the last line. If a smaller display is fitted, it will appear the same as the top, leftmost corner as a larger display would appear.

Thus the display operates fairly in-

Features & specifications

* *Shows two voltages, two currents and one temperature reading on a 16x2 LCD*
* *In alternative USB mode, ASCII text from virtual serial port is written directly to 20x4 LCD*
* *Panel meter input range: 5 x 0-4.096V*
* *Panel meter scaling: 2 x 0-4.096V -> 0-60V, 2 x 0-4.096V -> 0-9A, 1 x 0-3V -> 0-100°C*
* *Panel meter resolution: 58.6mV for voltages, 8.79mA for currents*
* *Panel meter update rate: 5Hz*

tuitively and can be easily controlled by any software that can write to a serial port. No data is sent by the USB display back to the host, so the receiving program should not expect to deal with this.

Construction

The Panel Meter/USB Display is built on a double-sided PCB coded 18111182, which measures 56 x 36mm.

The PCB overlay diagram, Fig.2, shows where to fit the components. As noted above, some parts can be left out for some applications. We will describe the installation of all parts, which will allow the unit to be used as either a panel meter or USB display.

The only surface-mounted part is the USB socket, and it should be fitted first. A soldering iron with a fine tip will make this easier. We recommend that you have flux and solder wick (braid) on hand for this step. A pair of tweezers can be helpful too.

Apply flux to the four pads on the PCB for the USB data and power signals. These are the four parallel pads to the right of the socket. Place the socket on the PCB; it should lock into place due to the two small posts on its underside.

Carefully apply solder to the pads and pins, ensuring all four are well attached. If there is any bridging, apply more flux and use the solder braid to remove it. Then apply flux paste to the four larger mechanical pads and solder them to their respective pads too. They are larger and will need more heat.

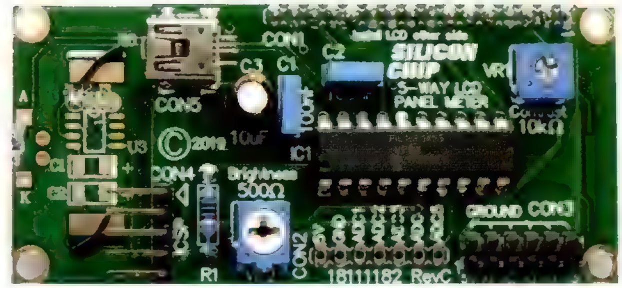
Next, mount the single resistor, followed by the two non-polarised 100nF capacitors. Follow with the electrolytic capacitor, which is polarised. It must be installed with its longer positive lead to the pad marked "+" on the PCB.

Now fit trimpots VR1 (10kΩ, "Contrast") and VR2 (500Ω, "Brightness"). Push them down, and they should both snap into place, after which you can solder their pins. If you are using a socket for IC1, install this next, ensuring the notch goes to the end closest to the USB socket.

If you have fitted the socket, gently straighten IC1's pins so that it will slot into the socket, then plug it in. If soldering IC1 directly to the PCB, start with two diagonally opposite pins. Once you are happy that the IC is flat against the PCB and oriented correctly, solder the remaining pins.

You can now mount CON2 and CON3. For CON2, you could use either a header or socket, while CON3 is designed to be fitted with a double-row male header to allow an IDC socket (plug) and cable to be attached.

The PCB sits neatly within the footprint of the 16 x 2 LCD panel, leaving the mounting holes clear. Using a female header on the PCB means it can be removed if necessary.



If fitting CON4, do so next. You can use a straight or right-angle header; we prefer the right-angled variety in this role as it allows the programmer to sit flat when connected. CON1 should be fitted last, as it also needs to be attached to the LCD. You may choose to solder it directly, or use a female header socket on the panel meter PCB to allow the LCD to be removed.

We recommend attaching the male header to the LCD first by soldering one pin and ensuring it is straight and flush with the LCD's PCB. Then solder the remaining pins. Before soldering the LCD to the main board, check that its pinout matches that shown in our design.

Most LCDs with a SIL header should have a pinout that matches ours, but checking this now can save much troubleshooting later if you somehow have one that's different (see Fig.1). If there is a pin mismatch, you can solder only the matching pins and then use insulated wire to make the remaining connections.

You may like to slip a piece of card between the two to maintain spacing while soldering. Check that your boards are orientated the same way as in our photos. If you are using a header socket to attach the LCD, plug in the male header before soldering. This will allow you to check that all the clearances are correct.

Programming IC1

This step is not necessary if you purchased a pre-programmed PIC.

You can use a PICkit 3, PICkit 4 or SNAP programmer to flash IC1 on the board via the ICSP header (CON4).

As we wrote in our SNAP review (May 2019; siliconchip.com.au/Article/11628), the SNAP programmer cannot provide power to the micro and

Parts List – Five-way LCD Panel Meter/Display

1 double-sided PCB coded 18111182, 56mm x 36mm#
1 16x2 character LCD with backlight (for Panel Meter, eg, Jaycar QP5521) ***OR***
1 20x4 character LCD with backlight (for USB Display, eg, Jaycar QP5522)
1 16-pin male header (CON1)
1 16-pin header socket (optional, to allow LCD to be unplugged)
1 7-pin header or header socket (CON2; optional)
1 2x6-way pin header (CON3; not needed for USB Display)
1 6-way right-angle header (CON4; optional)
1 SMD mini-USB socket (CON5; not needed for Panel Meter)

Semiconductors
1 PIC16F1459-I/P microcontroller programmed with 1811118A.HEX#

Capacitors
1 10µF 10V electrolytic
2 100nF MKT or multi-layer ceramic

Resistors
1 10kΩ 1/4W 5%
1 10kΩ mini horizontal trimpot (VR1)
1 500Ω mini horizontal trimpot (VR2)

#Programmed micros and PCBs are available from the SILICON CHIP ONLINE SHOP

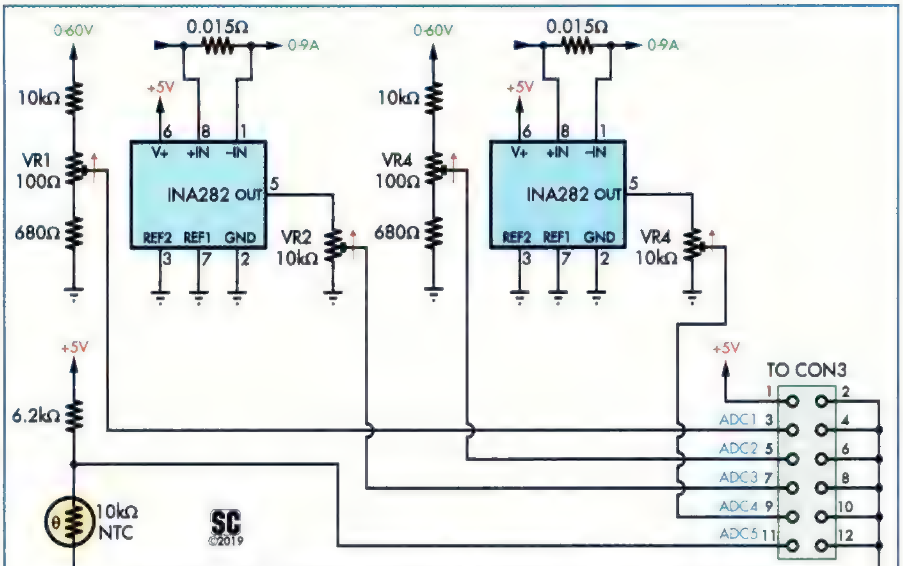


Fig.3: how to interface the Panel Meter to your own circuitry. If you're using low-side shunts to monitor current, you could use op amps to amplify the voltage across them to a suitable level for feeding to the Panel Meter. You could also use lower value shunts in combination with a higher-gain shunt monitor for less heating and power loss.

only supports low-voltage programming. So if you are using the SNAP programmer, you need to provide power via another source, such as the USB socket, and ensure that the low-voltage programming option is selected in the software.

Regardless, you will need Microchip's IPE (integrated programming environment), which can be downloaded as part of the MPLAB X IDE from: www.microchip.com/mplab/mplab-x-ide

In the IPE, select "16F1459" in the device drop-down menu and your programmer from the tool menu, if it isn't already selected.

Connect the programmer to CON4 on the PCB, lining up the two pin 1 indicator triangles.

Then click the "Connect" button in the IPE and ensure that the connection is successful, according to the display in the lower output window.

Then you just need to open the HEX file and click the "Program" button to upload it to the chip.

Connecting the panel meter

Details for connecting the panel meter to the Bench Supply are included in that article.

If you wish to use it for another purpose, then connect the 5V and ground pins to a 5V supply and the five analog pins to sources of appropriate analog voltages.

The ADC1 and ADC2 inputs are scaled to display 0-60V for an input of 0-4.096V, while ADC3 and ADC4 are scaled to 0-9A for 0-4.096V.

You will need to use a 10kΩ NTC thermistor wired as a divider with a 6.2kΩ resistor across a 5V supply to feed the ADC5 input if you are to get meaningful readings.

Fig.3 shows our suggested circuitry for interfacing with the Panel Meter. If you're using a different shunt value, you will need to use a different shunt monitor IC, or provide some gain at its output, to get at least 4.096V for a current of 9A, giving the correct scaling. That's regardless of whether your circuit will reach 9A.

Once the Panel Meter is connected to such a circuit, it simply converts the analog inputs and displays the measured values, and no other action is required. You may need to adjust the contrast and brightness, as described below.

Using it as a USB display

To use the unit as a USB display, simply plug it into a computer with a mini type-B to type-A USB cable.

You may need to install a driver, in which case the same driver is used as for the Microbridge. This is because the Microbridge uses the similar 16F1455 microcontroller in a similar role.

This should not be necessary for Windows 10, Linux or Mac users.

If needed, the driver can be downloaded from: www.microchip.com/wwwproducts/en/MCP2200

Once the driver is installed and the USB device enumerated on your system, it can be tested by using a serial terminal program such as PuTTY, TeraTerm or even the Arduino Serial Monitor.

Open a connection to the appropriate port and type characters into the terminal. You should see them appear on the LCD. If not, you may need to adjust your LCD's contrast and brightness.

The baud rate is not critical as the virtual serial port enumerated by IC1 does not use this information (as it might if it were connected to a downstream hardware UART).

Contrast and brightness

No matter what the brightness setting, the backlight LED should be on. If you cannot see anything on the display, the contrast probably needs to be adjusted.

Turn VR1 until characters can be seen clearly against the background. Once the characters are clear, you can then tweak the brightness.

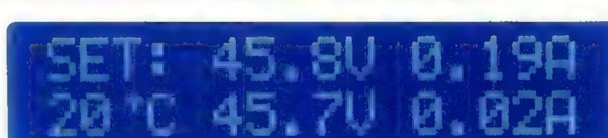
On the unit we have built, we had good contrast with around 1.8V on pin 3 of CON1, although this may vary depending on the specific display module used in your LCD.

If you have built the USB display and cannot see any characters, make sure you have sent some data to the terminal. If it is still not working, there may be a problem with the construction, probably to do with the LCD if the USB side is enumerating correctly.

Conclusion

While this was originally designed to replace multiple panel meters for our Bench Supply project, we've also turned it into a handy accessory for a computer.

It goes to show just how versatile the PIC16F1459 is. SC



When configured as a Panel Meter, the display should look like this, with voltage, current and temperature readings. If using it as a USB Display, the screen will be blank until it receives data from the PC via its USB serial port.

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Is this the ultimate in soldering convenience?

iroda® Solderpro 30W lithium-ion soldering iron

Reviewed by Nicholas Vinen

It's a relatively inexpensive and light soldering iron that you can carry around with you. It's ready to use within seconds and is capable of dealing with heavy wire and connectors with a minimum of fuss. And it recharges via just about any USB port, so it's always at the ready.

This is a new product for Altronics, and we think it's going to be a very popular one.

You would be familiar with the mains-powered, temperature-controlled soldering irons that are widely used for assembly and repair work.

They're quick to come up to temperature, well-regulated and adjustable, and their interchangeable tips make them useful for a variety of jobs.

But they have one major disadvantage, and it's the cables. That includes the mains cord which limits where you can use the iron, and the cable from the base station to the pencil which always seems to get in the way when you're using it. It also sometimes restricts how you can angle the pencil in tight spots.

Gas (butane) and battery-powered soldering irons have neither of these problems. You can use them anywhere in your home or office, or out in the field.

Inexpensive portable irons are usually gas-powered. The good news is that their internal gas supplies last for a while, and they're quick (if fiddly) to recharge. But the temperature control is usually a bit crude, and they can take a while to warm up.

They also have an open flame, limiting how you use them, and they cannot be used safely around flammable substances.

Gas irons are still the cheapest useful portable irons, but this battery-based Iroda Solderpro is not all that much more expensive.

And it's just so convenient to use. You pull off the plastic cover, slide the switch from its locked position, grab the pencil and hold down the power button.

Within about ten seconds, you're ready to solder. It's even quicker upon re-use.

It also has an integrated LED light, which illuminates what you are working on whenever you're pressing that button (ie, it's automatic). It's a brilliant feature – one of those things you don't realise that you're missing until you try it!

Because it's only consuming power while you're actually soldering, the battery seems to last a long time. It never ran out when we were using it.

The manufacturer states that it will last for 45 minutes of continuous use, which we would say means several hours of typical (intermittent) use. It would probably last all day if you aren't using it too heavily.

The recharge time is 3.5 hours, but we found it easiest to simply plug it in after each session to 'top it up' and that generally only took 30 minutes or so.

If you do use it heavily one day, you can just plug it in to recharge overnight.

The plastic case of the iron is moulded so that when you put it down, it rests on the bench such that it keeps the hot tip away from the surface. So it's easy to put down and pick up as needed.

When you've finished, you just slide the switch back into the lock position and re-attach the cap, even if the iron is still hot. This prevents the hot iron from touching anything if you need to put it away right away.

While it looks quite 'chunky' compared to a regular soldering pencil, we found it easy to hold and its relatively light 100g weight never presented a problem.

Recharging is super-convenient as it has the same micro-USB socket as so many phones, tablets and other gadgets do.

If you have an Android phone (and it doesn't have a Type-C socket), then you will already have a suitable charger – but it can plug into virtually any PC USB port or supply to charge.

A red LED illuminates as it's charging, which changes to green when it's finished.

Temperature regulation

Essentially, as you hold down the power button, the tip continues to heat up, only stopping at around 600°C. This means that you need to regulate the temperature yourself when working on smaller components.

I asked Tim Blythman to try it out, and he commented that it was easy

The basic Iroda Solderpro 25L iron is powered by a rechargable lithium-ion battery giving up to 45 minutes continuous usage per charge (but much more with typical operation). It is supplied with a single conical tip. It looks "chunky" but is quite well balanced and feels good in the hand (Altronics Cat T2690A).

to accidentally burn the board if you held the power switch on for so long!

I did not run into that myself, probably because I tend to make solder joints relatively quickly, only holding power on for long enough to form the fillet. It then cools down slightly between each solder joint, but only takes a second or so to be ready for the next one.

This iron is particularly well suited to such a usage pattern.

The only complaint that I have is that the iron supplied for this review (Altronics Cat T2690A) only came with a single, large conical tip. While I found this fine for general-purpose and through-hole use, it is a little on the large side for working with many SMDs.

For a little bit more money, you can purchase the Cat T2694A soldering iron kit. This includes a carry case, stand, cleaning sponge, some solder and (most importantly) a hot knife and a hot air blower.

The hot air blower would definitely come in handy when soldering SMDs.

Conclusion

Altronics have given us the choice of returning the review sample or paying for it, and we will be keeping it because it's just so handy for quick jobs.

Quite often we have a piece of equipment on the test bench and want to make a small change to see its effect, eg, adding an extra capacitor or changing a resistor.

Rather than unplugging everything and dragging it over to our workbench area, or unplugging a mains-powered iron and bringing it over to the test bench, we can just pick this iron up and make the change within seconds.

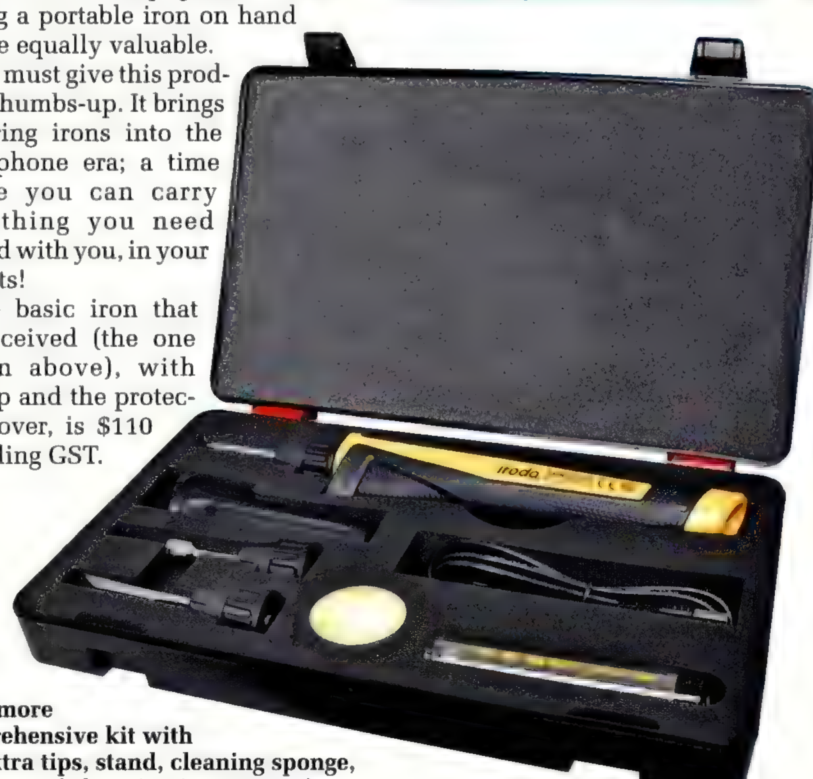
And for those times when we may need to work on equipment 'in situ', having a portable iron on hand will be equally valuable.

So I must give this product a thumbs-up. It brings soldering irons into the smartphone era; a time where you can carry everything you need around with you, in your pockets!

The basic iron that we received (the one shown above), with one tip and the protective cover, is $110 including GST.

It can be purchased from your local Altronics store (Cat T2690A), or their website via siliconchip.com.au/link/aav3

The more comprehensive kit including more tips (shown below), which I am recommending (Cat T2694A), is $169 including GST and can be found here: siliconchip.com.au/link/aav4 SC



Here is the more comprehensive kit with two extra tips, stand, cleaning sponge, solder, etc. (Altronics Cat T2694A).

VINTAGE RADIO

By Fred Lever

1930s "Vogue" radio restomod

Sometimes our contributors simply describe vintage radios. Other times they fix them up or even restore them. This goes way beyond that. It's a "restomod" – taking parts (or in this case, a part) from an old radio and putting newly built electronics inside, either to improve it, or because the original components are long gone. While most of the radio is new, it was built in the style of a 1930s radio.

I had shelves in my workshop made from scrap materials. Some of the timber came from the cabinets of discarded radios and TV sets. One piece was the front panel of an old 1930s style radio. I remember that it had glass bottle valves, a circular tuning dial and a very heavy loudspeaker. The workings of the set went to the tip, and I used the timber parts.

A couple of years ago, I was pulling the shelves down in a workshop rearrangement, when out came the front panel, complete with its brass escutcheon proclaiming it to be a "Vogue"!

It was in remarkably good condition considering how it had been used. But there were still quite a few scratches on it, and the timber on one side was soaked with motor oil.

Some web searches and forum posts gave me information on "Vogue" radios but unfortunately, none of this information matched with what I had. Based on what I remembered of the chassis construction, it was a cut-price radio, unlike the 5-8 valve, 3 or 4 knob Vogue radios I found on the web.

It had only two knobs: tuning and volume. The power switch was in the two-wire power cord which had a bayonet plug, which you connected to a double adaptor in a ceiling lamp. I remember this because we used the radio for a short time but then scrapped it when it failed.

That may seem amazing in this day of vintage preservation, but back in the 1950s and 1960s, millions of radios were scrapped as television came in. I remember one large radio store in town used to burn hundreds of radios at a time as they were traded in for TVs and transistor radios!

History

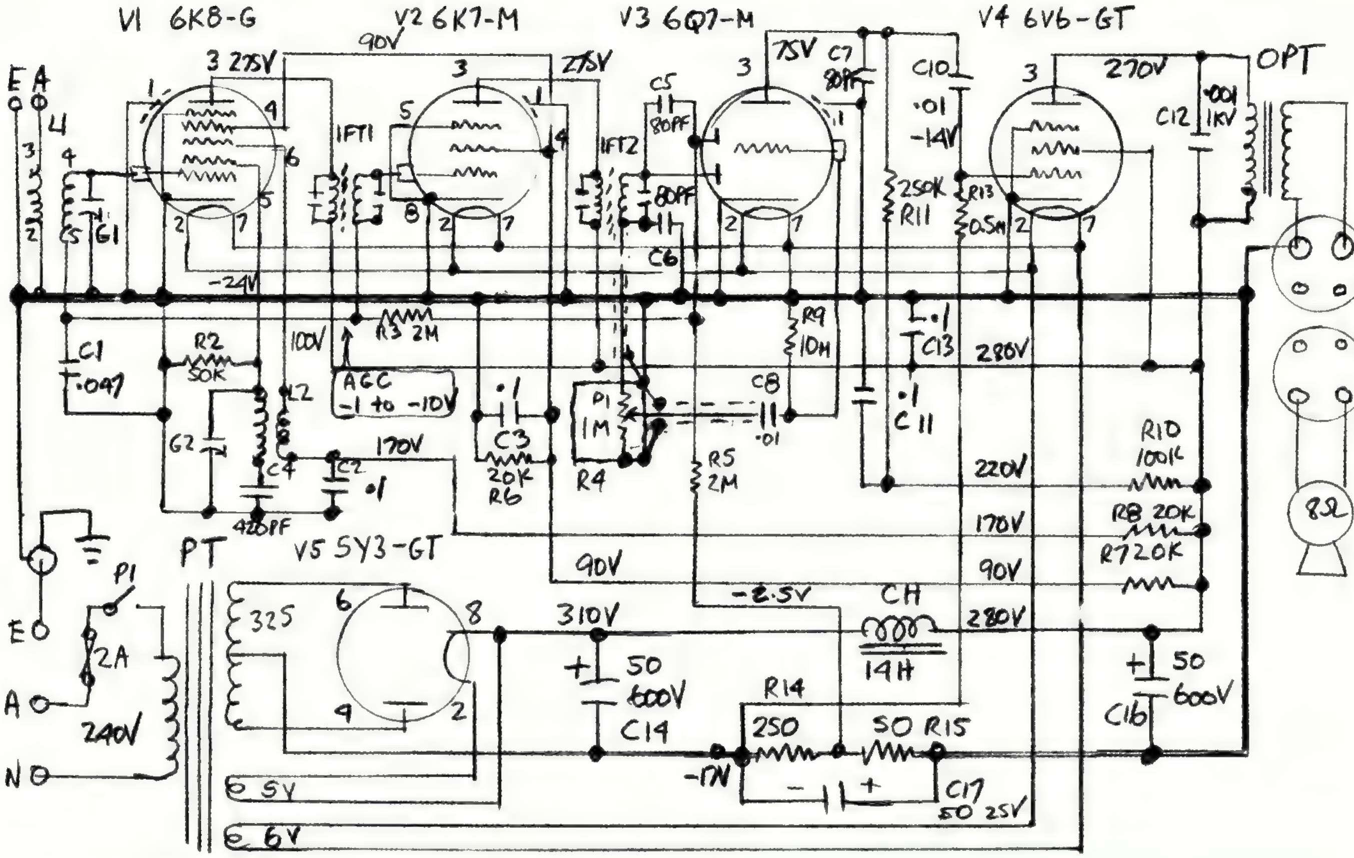
While the restoration detailed below was in progress, I found out a little more about this set from a vintage radio forum member. They identified the escutcheon as part of a type of dial assembly provided by Efco Mfg Co, called the "Lion".

The set may have been a low production private factory set or even a kit set from one of the radio type parts shops or retailers re-using the name Vogue. I lean towards the theory of this radio being built from a kit, as I used to see kits advertised in "Radio and Hobbies" using Australian-made parts. So my plan to recycle parts from Aussie radios of the period seemed like a good one.

Beginning the restoration

I cleaned the front panel up with degreaser and water, then prised off the ornaments and unscrewed the precious escutcheon and put them aside. Then followed a few hours of sanding back the veneer finish to remove some of the horrors, giving a better view of what was left. The veneer was badly damaged but I decided to polish it anyway and use it as-is.

I achieved a reasonable state with the front panel and the dimensions of this gave me a starting point to build a suitable chassis. Looking through my junk box, I realised that I had a handful of RCA metal case valves and as they were introduced in 1935, I decided to



The circuit used for this Vogue radio is loosely based off the circuit used in the AWA Radiola Model 84, 193, 194 and 501, all sold from 1939. You can find the Model 84 circuit diagram at www.radiomuseum.org/r/amalgamate_radiola_84.html

make a classic 1930s superhet with five valves and drew up a preliminary circuit.

Circuit description

It's a superhet AM broadcast band receiver. The aerial picks up radio signals and the tuned circuit of coil L1 and tuning capacitor G1 makes it selective for the tuned station frequency. This signal is then fed to the control grid of the 6K8G converter (V1).

V1 amplifies the signal and also mixes it with an oscillator signal which tracks the station frequency with a 455kHz offset, set by inductor L2 and the other half of the tuning gang, G2.

The output of V1 is a mixture of the tuned and oscillator signals, which produces a strong difference product at 455kHz. Coupling transformers IFT1 and IFT2 are resonant at this intermediate frequency, so they pass the signals at this frequency only and rejecting the higher carrier and sum-product frequencies.

IF amplifier valve V2, a 6K7M, amplifies this IF signal and its output is fed into IFT2 which then couples to a diode in V3, a 6Q7M dual diode/triode. This, in combination with 80pF filter capacitor C6, demodulates the audio and it is then fed to 1MΩ volume control pot P1.

The audio signal is also filtered to remove the AC audio component by 2MΩ resistor R3 and 47nF capacitor C1 and the result used as the AGC control signal, which alters the DC bias of the control grids of both V1 and V2, reducing their gain when tuned to stronger stations.

The audio signal from P1 is then fed to the control grid of the triode in V3, which acts as an audio preamplifier, and the output is coupled from its anode to the control grid of audio amplifier valve V4, a 6V6GT, via a 10nF capacitor (C10). It's configured as a Class-A amplifier and drives the primary of the output transformer, which couples the signal to a modern 8Ω loudspeaker.

V5, a 5Y3GT, is used to rectify the output of the mains transformer PT, to produce a 310V HT rail which then passes through an LC filter to remove ripple, before feeding the anodes of the other valves. Each one receives a different HT voltage as set by various dropping resistors, to best suit that particular valve and the way it is being used.

The mains transformer also has 5V and 6V AC windings to drive the valve

The front panel of the Vogue radio had torn mesh and was the only part remaining of the set. The original radio was likely sold as a kit set or small production run. The emblem on the cabinet depicts a muse (likely Erato) playing a lyre and was manufactured by Efco, based in Arncliffe.

heater filaments. Only V5 needs 5V; the others have 6V heaters.

A trial chassis layout

I took a sheet of 0.7mm galvanised steel I bought from Jaycar and tried various layouts by arranging the parts on a generously sized rectangle. From this I determined that the chassis would need to be about 355 x 230 x 50mm. I made sure to leave plenty of room around the components, as the cabinet would be pretty large anyway.

I planned to mount most of the smaller parts on tag strips and wire the set with coloured wires, with the major components laid out neatly in a rectangular grid. I wanted to use as many period parts as possible.

The next step was to fold up the chassis. I cut out the metal using a jigsaw and shears and folded it up using a small press, plus a hammer and dolly in a vice. I ended up with one large sheet and some smaller plates, which I then pop riveted together.

I made up a box frame to carry the side and top panels from timber flat bars. The dimensions were to suit the existing front panel, with enough depth to accommodate the chassis. I chose a 12in, 8Ω speaker from Jaycar, mounted on a baffle board attached to the main frame, as the front panel is too brittle to take any screws or weight.

I made up the frame and did a trial fit of the chassis, to locate the control spindles and to make sure nothing would be fouled. I made a board for the speaker and clamped it in position, to make sure that it would fit as well. There were no major snags, so I was then able to firm up a lot of details.

My woodworking skills are very limited, so I assembled the cabinet using butt joints with plenty of glue. Once the frame was squared up, I clamped the front panel to the frame and glued it in place. It was warped like a banana and I had to clamp it every 150mm or so, to make it sit straight and pull it onto the frame.

The case was made from plywood, while the frame and speaker baffle was made from timber. The chassis had the components loosely placed on top to help align the location of the tuning gang and dial.

With that tacked on, I then put in some more flat bars for the chassis to sit on and glued them in place. Finally, I had a mounting place for the chassis.

After mounting the speaker and its frame, I taped some gold coloured cloth on the frame with the back side of the cloth at the front, to give a matte finish through the fretwork.

The side panels had to be bevelled to mate with the front panel before they could be fitted to the cabinet. Not having the skill to produce a bevelled edge, I did the next best thing and inserted a section of triangular timber strip up against the front panel on each side, thus presenting a taper for the front panel and a flat face side panels to butt up against.

I made a lid for the cabinet from 7mm plywood and added a centre brace underneath, in case heavy items were placed on top. I did not want the plywood to buckle inward.

With that glued firmly in place, I then cut the side sheets from 9mm plywood with my trusty jig saw. I made them a few millimetres larger than necessary and glued them into position. Then I profiled the edges with an angle grinder, to match the frame, and smoothed the whole lot using 120 grit, ready for finishing and staining.

I then decided to test the gluing of the frame and gave some of the rectangular bar sections a whack with a hammer. The bottom crossbar fell out, so apparently, glue was not good enough by itself! I added screws at each corner to peg the joints. I threw a few more screws in at the other main joints as well, not wanting the cabinet to fall apart later.

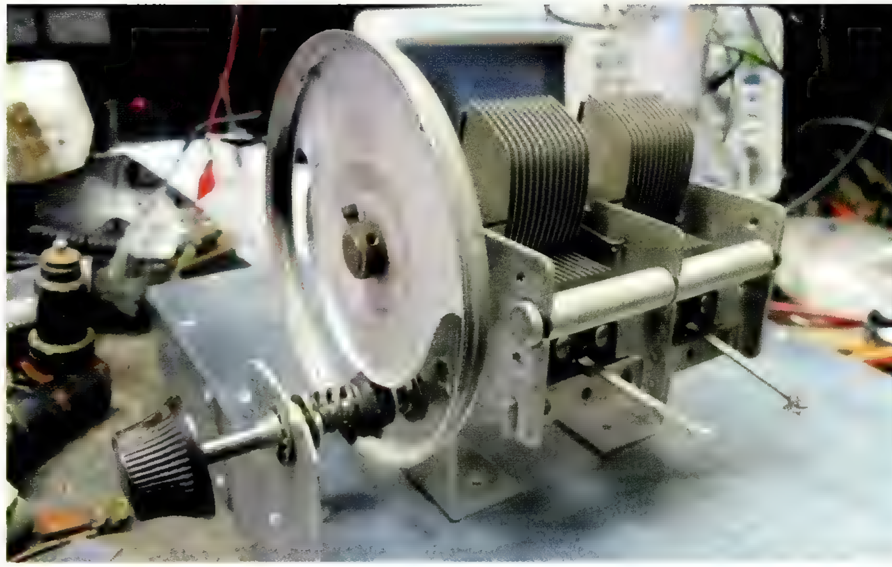
The next step was to paint the interior surfaces flat black. Once that dried, I sanded the other faces (apart from the front panel) using 400 grit sandpaper and applied coats of cedar stain to pull the shade of the white timber towards the front panel shade.

I gave it several coats, sanding again with 400 grit in between, until I achieved the shade I was looking for and the ply flatted off without too much wood fibre standing up. The stain went darker upon drying so in the end, I overshot a bit.

I then buffed the wood with oil and then buffed a coat of silicone-based

The chassis was made from pieces of galvanised steel, folded with a forming press and held together with rivets. It is about 355 x 230 x 50mm.

The sides and top were attached to the case, with coats of cedar stain applied to the outside.



The tuning gang was refurbished from an AWA radio. The drum it came with was then drilled to form a circular hole that the spindle could travel across. The spindle was cut from a metal rod.

car polish on top, giving an "antique" look with a low-gloss finish showing all the scratches, bumps and fake "wear" marks.

Tuning mechanism

I now needed to think about the tuning gang drive mechanism. The front controls from the chassis have to match the holes in the front panel, so there were fixed centres to work from. The proximity of the spindles indicated that the original dial drive was probably a friction drive, direct onto the tuning gang drum, so I decided to mock up a drive and make sure that it was possible.

I pop-riveted a temporary plate to the front of the chassis, and after some fiddling, I worked out what was possible and how to fit this into the space available. I fitted a bush to the temporary plate and I then cut a short piece of quarter-inch rod to form a spindle. I cross-drilled the spindle for split pins and slid a tension spring and two washers onto the spindle so they would grip a disc.

The tuning gang I used was from a junked AWA chassis; the drum on the gang was a nice size to make the friction plate. I drilled the drum and cut out a semicircular section for the spindle washers to grip and drive the gang through half a turn.

Here is where I made a stupid mistake. I set the whole thing up and fabricated brackets to hold the gang at the height so that the spring-loaded washers tightly gripped the flat face of the drum cut-out and it drove the gang nicely. But I chose the inner circle to drive; thus, when I turned the spindle clockwise the gang turned anti-clockwise!

I had to rework the brackets to raise the gang for the spindle, to work on the outside circle of the cut-out. But I had removed most of the front face on the outside so now the washers would not grip reliably. I had to fit a rubber grommet to the spindle as a tyre, which drove against the inner surface of the drum. It worked well and rotated the drum in the same direction as the knob.

With the drive mechanism sorted, I mounted the gang onto the chassis and checked it in the cabinet and found I had a space of about 20mm in front of the drum to fit a dial. I would tackle that later but at this stage, envisaged a stationary card lit from behind with a pointer mounted on the drum.

At this point, it would have been easy to cut and re-drill the gang supports to get the dial drum outside diameter precisely in line with the escutcheon opening, but this point evaded me at the time.

Chassis layout

I then turned my attention to assembling the chassis. I needed four tuned coils. I had a junked model 84 AWA set with the oscillator and IF coils and after searching through my odd coil box, I found an aerial coil that looked promising. I needed the aerial coil to cover 600-1700kHz, the oscillator coil to about 950-2150kHz and the IF coils would then be tuned to around 450-455kHz.

I tested all the coils using a signal generator and a CRO, looking for a resonant peak when applying a varying frequency signal. As I did this, I kept in mind that the frequencies would be somewhat reduced when built into the set due to stray capacitances.

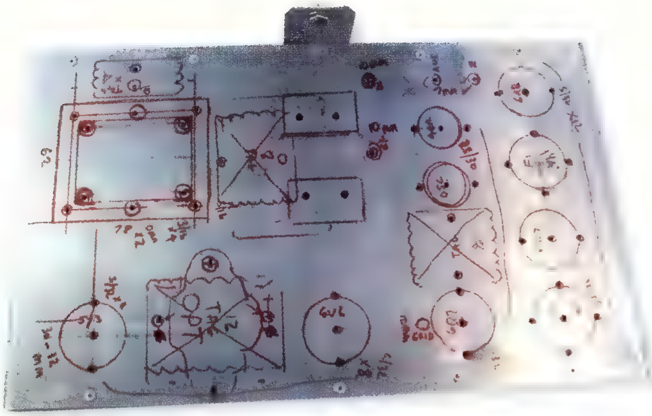
I added a 420pF padder to the oscillator coil and found that it would then resonate from 960-2130kHz. The aerial coil resonated from 475-1550kHz, again in the ballpark.

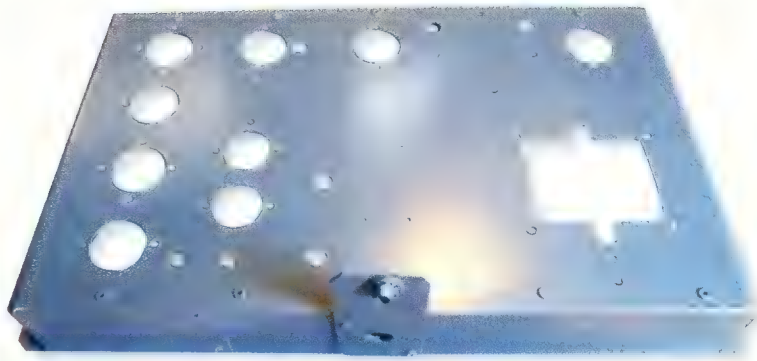
While IFT1 gave identical 400kHz peaks on both windings, IFT2 was a problem. One adjusting screw was wound all the way out and jammed – with the screwdriver slot broken off! The good winding resonated at 405kHz but the broken side was at 350kHz. Freeing the adjusting screw just moved the resonance down to 300kHz.

At some stage, the screw had been wound right out in an effort to get near the correct setting; the exposed thread had a dab of red paint showing this was a factory setting! The set probably still worked but must have been down on sensitivity.

I pulled the coil apart and removed the peaking capacitor; it measured 120pF. Without this capacitor, the coil resonated at 650kHz, so I judged the coil was still usable. I fitted a 56pF capacitor instead, and the coil then resonated at 405kHz with its slug at mid position, the same as the others.

The oscillator coil from the AWA set was unshielded, but I wanted it in a





The chassis was marked with the component layout and then holes were drilled for the valve sockets, power transformer and IF transformers. After this, the chassis was coated with primer and painted blue.

can, like the others. I fitted and tested it in a scrap square can to match the aerial coil, which came from an unknown receiver. I planned to connect the tuning gang fixed plates and the converter grid cap above the chassis, so drilled the cans for the coil grid winding to come out the top.

The tuning gang already being located, I then marked up positions for the coils, the valves and IF coils in the front end of the set. I kept these parts as a compact group on the left and placed the detector and audio output parts along the rear of the chassis. That left the right side of the chassis for the power supply parts.

I used the circuit diagram as a guide and visualised the required layout. The aerial and oscillator coils fit right beside the tuning gang, to get the shortest connecting wires.

I positioned the aerial and Earth connectors at the front, to avoid having the aerial wire near the IF stages. I later realised that I could have put the terminals on the back of the chassis and routed the wires around to the front.

The valve sockets and the coils were orientated for logical lead placement. I drilled four holes for the two-bolt IFTs, to give me several options later. You have to think in three dimensions and make sure that all securing bolts are accessible and nothing hits anything else. There are a few holes required for wires to come from under the chassis to above, eg, grid cap leads, dial lighting and gang connections.

It's a bit like laying out a PCB. Some of the resistors and capacitors will connect direct, point to point, but I placed small pieces of tag board in strategic locations to hold parts where the lead length was not critical. I also added a socket to the rear of the chassis for the speaker leads.

The choke and power cord needed holes too, as did the separate Earth screw on the right-hand side. I used a Jaycar cord-grip gland to secure the power cord. I drew the component outlines with a Sharpie pen first, then drilled all the holes once the pilot marks were squared up.

Having drilled all the required holes, I cleaned up the chassis, sprayed it with etch primer and then blue Galmet hammer paint.

Speaker transformer

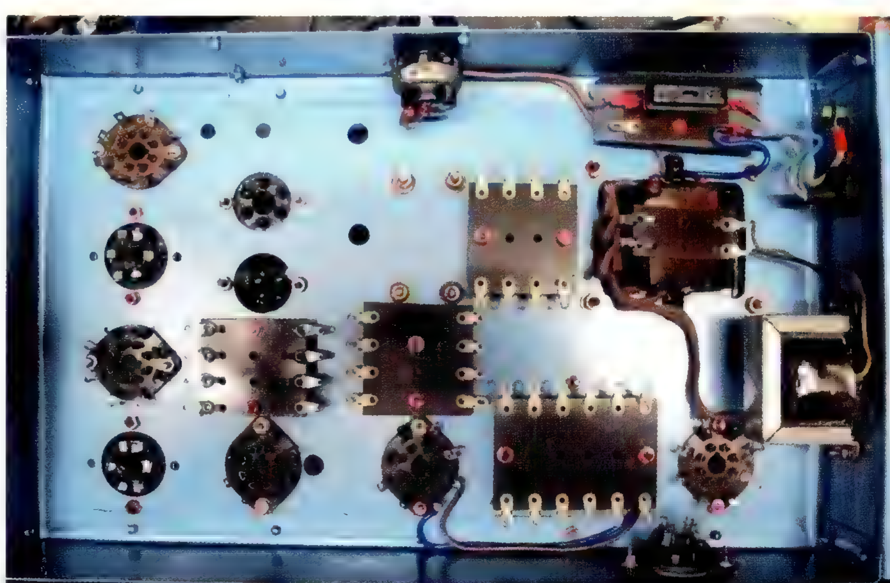
As the 6V6 audio output valve does not have earth-shattering output power, I selected a Jaycar MM2002 (type 2215) 15W multi-tap power transformer to match it to the 8Ω speaker. With a 230V AC primary and 15V AC secondary, that gives a turns ratio of 15.3:1 (230 ÷ 15).

As the speaker is an 8Ω unit, the impedance seen by the valve will therefore be 1.88kΩ (8Ω × 15.3^2), which is a bit low. If I used the 9V tap, the impedance would be 5.2kΩ which is a bit more like it. A 6V6 in class A with 250V at the plate is specified for driving a minimum load of 5kΩ.

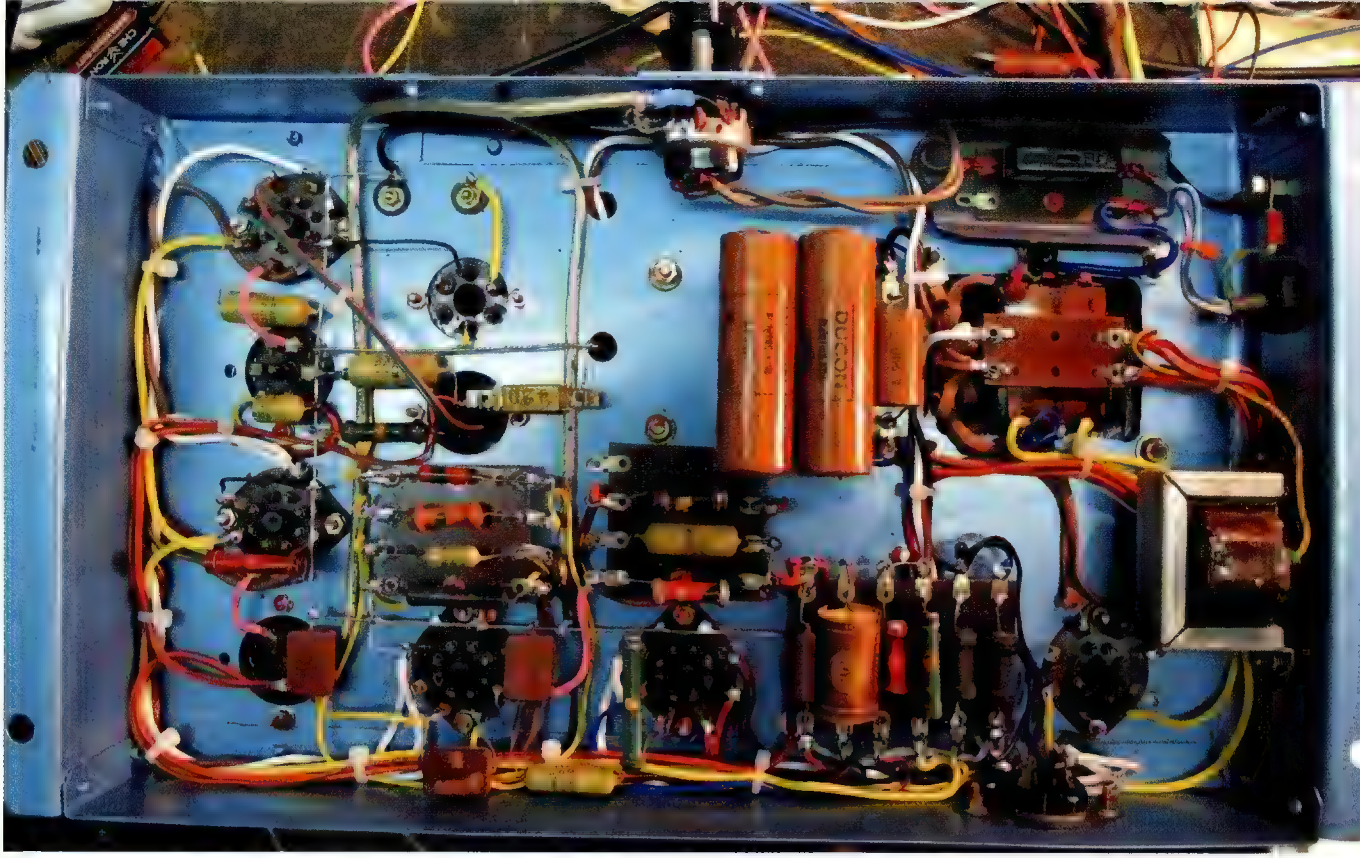
I wired a 6V6 and a 6Q7 together on the bench to drive the transformer and to test for the best of my valves to use in the audio section. This lash-up was powered from my trusty variable power supply, which has 6V AC and 0-350V DC outputs.

The result was that the 6V6 gave about 4W output with 250V DC at the plate and the Jaycar transformer gave identical results either interleaved or air-gapped, which indicated there was a surplus of iron and no DC offset saturation with either stacking.

I left the transformer air-gapped, and on the final test, it was good for a frequency response of 80Hz-5kHz at 4W using the 9V tap. The impedance curve was fairly flat with a useful output from 2-16Ω, peaking at 6Ω. So it would suit the 8Ω speaker nicely. The



The chassis at an early stage of assembly, with various sockets mounted, some wiring done, and a fuse connected to the volume pot's on/off switch.



The complete chassis is shown above. Note the stiff wire used as an Earth bar from the external Earth terminal at upper left, terminating at the tag strip at lower right.

output transformer started ringing at higher frequencies and at the clipping power level. A capacitor across the primary reduced this tendency.

I did not employ any negative feedback in the circuit, to keep it simple and keep the gain as high as possible.

I used 1930s parts in my tests and found the only critical component was the 6Q7 plate decoupling capacitor. Any leakage here would drive the 6V6 to maximum plate current (about 90mA) and choke off the audio. So a low leakage capacitor is a must.

Chassis assembly

It was time to attach the basic bolt-on components such as sockets and tag strips. RF components aside, I wanted to mount them on tag strips. I drew up a rough wiring diagram from the circuit diagram and pencilled in where the parts could go.

From that, I arrived at the number of tag strips needed and squeezed them into the chassis as required, around the valve sockets. These were washed in methylated spirits and given a buff up, then bolted to the chassis. Then the transformers were given a black or lacquer finish and also fitted.

I mounted the tuning gang and fitted the tuning coil and oscillator cans in an orientation that gave the shortest grid and plate leads. That did not work so well for the oscillator plate and grid leads, which can be seen running diagonally from the valve socket straight to the coil.

The grid lead for the converter was picked off the top of the tuning gang fixed plate connection, and the oscillator coil was connected through the can to the top of the gang. The IF cans were mounted for shortest signal lead length. I then fitted in the Earth bar which runs from the external Earth spring terminal, past the signal valve sockets and terminates on a tag strip with the HT divider components.

On its way, it picks up the shield and cathode points of pins 1 and 8 for each valve and provides a convenient bar to wire bypass capacitors and signal ground points to.

I didn't use the chassis itself for any ground or B- connections; I prefer to run two wires to all points on the circuit, keeping the signal B+ and filament feeds separate. That is how I make guitar amps, so I took the same approach with this radio.

Mains cable and power-up

I fitted the mains cable and fuse and completed the transformer primary wiring. I used a bulkhead gland to grip the power cord and attached the Earth to a brass screw. That screw is then wired to the single ground point of the circuit, where the tuning gang capacitors terminate.

I fitted a 2A mains fuse, then double-checked the power plug Earth pin continuity to all chassis panels. Then I powered up the transformer and checked all the secondary voltages and connections.

With all that satisfactory, I completed the filament wiring and plugged in a set of dummy glass valves, and checked that all the heaters lit up.

That also gave me the opportunity to check the 5Y3 rectifier valve insulation and confirm B+ output at the filament, with the plates at about 450V DC. With no smoke or flames, I then proceeded to wire in the power supply components and the 6Q7 and 6V6 circuits, to test the audio section for correct function and the smoothing DC component's suitability.

The volume control required shielded cable as the signal passes from the rear of the chassis to the front and back again. I probably should have mounted the control on a bracket at the rear and fitted a long extension shaft through a front power switch.

Components and wiring for the audio and power supply were installed but without the 6V6 and 6Q7 to start with; just the 5Y3 rectifier. I powered the set up via a Variac and monitored the back-bias resistor voltage to give

me an idea of the current drawn. I watched the surge and forming current of the electrolytics, which was around 100mA at first but dropped as the capacitors formed.

After a minute or so, the current dropped to a negligible level, so I slowly advanced the supply voltage to 230V AC. The HT peaked at 450V DC with little current flow, and nothing was getting hot, so the forming action was finished. The filament voltages were normal, so I shut it down and plugged in the 6Q7 and 6V6 valves.

The amplifier stages worked first up, drawing a total of about 50mA, resulting in a back-bias voltage of -15V. I injected an audio signal into the volume control and power tested with a sinewave and a dummy load. The 6V6 gave an identical power output as it did during my bench test, with a similar frequency response.

Front-end testing

Working backwards, I continued by wiring the detector and converter sections but only plugged in the 6K7. To see how the IF transformers would react, I injected a 455kHz signal into the plate pin of the 6K8 socket.

The signal got through to the 6K7, and was then amplified, but IFT2 did not seem right; there was no peaking with slug adjustment, just a change in amplitude.

This did not bode well, but I pressed on, leaving the slugs set for an overall peak at 455kHz. When the 6K8 was plugged in, a stable oscillator signal appeared at the 6K8 plate and this could be adjusted over a range of 1000-2500kHz via the tuning knob. I checked the DC voltages and they were more or less as expected. There was -17V back-bias with -2.5V at the tapping point for the RF system. The HT was 280V DC and 70V for the screen supply.

I injected a modulated RF signal into the aerial circuit and was rewarded with a signal at the 6K8 plate that included a strong 455kHz component, giving me a tuning range about 500-2000kHz which more than covered the AM broadcast band. So it seemed that the basic tuning coil set was suitable.

Substituting an external aerial for the RF generator allowed me to tune across the AM band and pick up the spectrum of local Sydney stations from 2FC way past 2SM, and it was great to hear actual radio stations!

Troubleshooting

However, all was not well. The signal at the diodes of the 6Q7 was way below expectations, and the volume control needed to be at maximum to get a reasonable output for the speaker – plus there was no AGC voltage.

There was indeed a problem with IFT2. The only thing to do was to pull it out and substitute another coil. I found a Kingsley coil in my junk box which was of a similar age and frequency range. I checked it for resonance and wired it in. Immediately, I could peak the IF and had about a volt of audio signal available at the volume control.

Better still, I found I could slide the Kingsley IFT can inside the faulty AWA coil can, so from the outside, both IFTs look the same.

But I still did not have any AGC voltage, and the set was out of control, with nasty distortion coming from the detector and IF sections. I checked the resistance of the AGC line to ground and instead of megohms I found it to be a varying low resistance of about 2kΩ. This was shunting the AGC voltage to ground.

This was caused by 2MΩ carbon resistor R5 which had a resistance which varied if I wiggled it! With that replaced, I could get up to 20V off the unloaded diode and once connected back to the grid system, I saw between 1-10V depending on signal strength.

Interestingly, with the coil set working well, I could dispense with the trimmers on the gang. The tracking of the gang sections finished up giving good enough matching so that trimming did not increase the signal level, even at the top end of the scale; removing the trimmers simplified the build.

The signal was now as clean as you could expect and with the IFTs all peaked, the set was 'lively' with plenty of background chatter off station with low AGC, and an almost silent background when tuned in to a strong station. However, there was a level of hum and buzz that was not nice and needed investigating.

The hum was mostly 50Hz, with some buzz mixed in. I realised that I had forgotten to Earth one side of the heaters. Earthing pin 7 of V1-4 gave better results than pin 2, and that reduced the 50Hz level right down, leaving the buzz to deal with. I noted that the buzz varied with the volume control setting, being almost non-existent at full volume and worse at half volume.

This was because I had used a switch pot to switch both mains and millivolt-level audio signals. Placing mains wiring anywhere near a high-impedance grid circuit is not a good idea. The obvious thing to do would be to get the mains wiring right away from the audio wiring or shift the control function to a less sensitive part of the circuit, such as the output valve grid.

However, I persisted and found that by re-dressing the mains wire around the volume control and changing the grounding point for the shielded cable, I reduced the buzz to a minimum and left it at that. In normal listening conditions, no hum or buzz can be heard.

DC voltage checks

I then decided to check the DC operating conditions of the valves. The 6V6 output valve was biased at -14V and with 280V on the plate, was within specs. The 6Q7 generates its own grid bias and amplified cleanly with a gain around 15 times, with a plate voltage of 80V.

The 6K7 and 6K8 were working OK but with screen voltages a bit low, at around 60V. I changed the divider circuit to push the screen voltages to 90V, and the IF signal level increased noticeably.

The set draws about 60mA with the output valve accounting for most of that, and after a couple of hours, nothing was overheating and the voltages

The faulty AWA IFT2 was replaced with a Kingsley coil which fit perfectly inside the AWA can. However, this did not fix the lack of AGC voltage.

and currents were unchanged.

Tweaking the valve lineup

The valve lineup shown in the circuit diagram wasn't finalised until this stage, as I became a bit of a "valve jockey", substituting various compatible types to find the best combination.

I found that a particular metal 6Q7 had a bit more gain than the others. The 6K7s all worked about the same, so I picked the nicest-looking one.

The converter choice was interesting as I had many metal, glass GT and G types to pick from. After a lot of to and fro, I settled on a particular new-old-stock 6K8G that worked quietly with high gain and no sign of instability, as it is a shielded construction.

Not knowing a great deal about converter design, I took the easy approach and merely selected the best-sounding valve.

Most of the capacitors I used are the 1960s mud-brown types. Low-value capacitors are all original "Simplex" mica moulded types. I didn't use any 1930s or 40s wax or moulded paper capacitors as they are all quite leaky now.

The resistors are mostly carbon wire end types plus a few wirewound. The electrolytics are 1960s 600V TV plastic types, hidden in some older "Ducon" cardboard tubes.

Dial lighting and scale

The chassis was offered up to the cabinet again and lined up, to check the spindle length was correct to fit knobs and to see what room there was to fit the dial scale. It was then that I discovered the gang spindle was not in the centre of the dial escutcheon. I missed by about 15mm vertically for one reason or another, thus making a direct 1:1 dial impossible.

The other choice I had to make was between a fixed scale and moving pointer, or fixed pointer and moving scale. What then followed was a series of trials, making up cardboard dial scales. The best solution I came up with was a porthole escutcheon with a fixed pointer at top centre and a simple moving circular dial behind that, bolted directly to the gang drum, with the stations and frequencies marked on it. In the end, I blanked off most of the curve in the escutcheon with a plate, leaving a wedge-shaped port with a fixed centre pointer.

I then mounted a simple dial plate off the gang drum. The dial plate was then marked with stations and covered with a plastic disc to keep it clean. Working on the smaller radius of the lower escutcheon opening reduces the usable circumference and crowds the station markers together, but that's what I am stuck with.

Next time, I will know better and position the escutcheon to use a larger diameter for greatest scale length.

The remaining work concerned mounting a dial light above the pointer position, making up a speaker connecting lead, finalising the exact position of the chassis in the frame, drilling the chassis securing holes in the frame and fitting a set of temporary knobs to operate the set. I will find a more suitable pair at some stage.

It's the old story; I have plenty of knobs that look the part by themselves but not two that look completely right together.

Conclusion

The set is sensitive enough to pick up local stations with a short lead on the aerial terminal, but works much better with a 10m outdoor aerial. The 6V6 gives adequate listening level for room use. The tone of the finished radio is slanted toward the bass end, mostly due to the big speaker I used.

I did an audio frequency response check from the RF modulated signal generator and found it to be flat from 200Hz to 3kHz, with -3dB points at 110Hz and 6kHz. But the 15in speaker skews that towards the bass end. The cabinet could do with a tweeter, but enough is enough; this is 1935, after all!

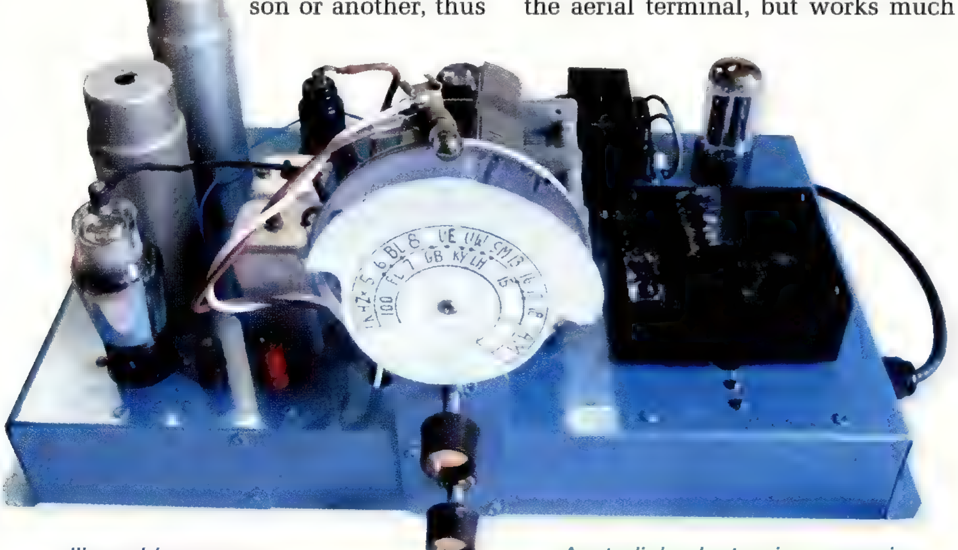
One of the last jobs was to level the legs of the cabinet and drill the frame for the hold-down chassis bolts. The cabinet had warped over the couple of weeks it took me to finish the chassis and rocked diagonally by about 3mm. I shortened the longer leg by about 2mm, then fitted some stick-on felt feet – the cabinet finally stood square.

With the chassis pushed into final position and the dial lined up, I pencilled through the chassis holes and drilled the timber out double oversize, then bolted the chassis in place with 3/16-in bolts.

The set now has the external appearance of a well-worn and faded 70-year-old cabinet, but it has a spick and spiffy chassis inside with RCA octal type valves, which were just plausible in 1935. It's as if some were later replaced with glass types and the capacitors were later replaced with 1960s models and re-wired with modern plastic cable.

The set sits in my little collection as representing a 1930s radio and it was fun to build, and learn a little more about RF circuits and valves.

Extra details on this set can be read in the forum post Fred Lever made at: siliconchip.com.au/link/aapw SC



The finished dial was drawn by hand onto a piece of stiff paper.

ASK SILICON CHIP

Got a technical problem? Can't understand a piece of jargon or some technical principle? Drop us a line and we'll answer your question. Send your email to silicon@siliconchip.com.au

Capacitor type question (MKT vs ceramic)

I'm a newbie building your Programmable Ignition System (March-June 2007; siliconchip.com.au/Series/56). I'd love to know the difference in properties between MKT and ceramic capacitors. There are both types of the same rating on the board. How does the designer choose one or the other? (R. F., Somerset, Tas)

• Generally, we will use ceramic capacitors for values under 1nF mainly because low-capacitance MKT types are harder to get. MKTs are good general-purpose capacitors, and they also offer low distortion in audio circuits (ie, they have decent linearity).

Ceramic capacitors are better for use at high frequencies compared to MKT types. Ceramic capacitors are made with several different ceramic dielectric materials which give different properties. C0G/NP0 types (usually 100pF and under) offer excellent linearity, but other dielectrics used for higher values have poor linearity and also suffer from very bad voltage coefficients.

So for larger values, MKT capacitors usually offer superior performance, except perhaps at very high frequencies such as may be present in FM radios and similar. Ceramic capacitors are almost used exclusively at higher radio frequencies due to their low effective series resistance at high frequencies. The low temperature coefficient of C0G/NP0 types is also invaluable in tuned circuits.

But usually, it is not critical whether MKT or ceramic capacitors are used in most circuits. They can often be interchanged with no effect.

MKT capacitors are very similar to 'greencaps' as they both use a polyester plastic dielectric. The main difference is that MKT capacitors are supplied in standard-sized rectangular packages while greencaps (which may also be red) have a pillow-like shape and have a wider variety of sizes and lead spacings. They have slightly different construction (metallised film vs foil), but it makes little practical difference in most cases.

RF Signal Generator power switch

I built the RF Signal Generator (June-July 2019; siliconchip.com.au/Series/336), and it generally works as expected. However, the power on/off only turned it on and not off. To make that part of the circuit work correctly, I had to increase the 1µF capacitor in series with the 270kΩ resistor to 10µF.

I'm also having problems with the frequency change control. Instead of stepping once for each rotational step, it jumps several steps in frequency, regardless of whether it is set for Hz, kHz or MHz. I changed the encoder to a different type (twice), but the results were the same.

I've discussed this with a few other people, and it appears this problem is not uncommon if the encoder programming has not been correctly debounced. Programming is an area I am not strong in so I can do little to prove one way or the other. I would appreciate any assistance you can provide. (P. M., Croydon, Vic.)

• The designer, Andrew Woodfield, responds: thank you for your observations. I've built four or five of these power switches now, and all have worked fine with the 1µF capacitor. However, I am likely using capacitors from the same batch, and your power source may be different from mine.

I'm glad that the 10µF capacitor solved your problem. But when I tried this value in one of my boards just now, it did not work well, and I had to change it back to 1µF to restore proper operation. I will ponder the circuit and see whether I can figure out why you need a different value to me. Perhaps switch contact resistance plays a part.

Regarding the rotary encoder, some low-cost encoders can produce significant contact bounce, extending beyond the time delays allowed for in my software. I have also encountered occasional problems when trying to turn the encoders very quickly (which is beyond the ability of the software to handle) or if a cheap encoder becomes worn.

I've used similar software to handle the rotary encoder in several designs, with many different (mostly cheap) encoders from different suppliers. I have generally found them to operate satisfactorily. My software is designed in such a way that debouncing should not be critical.

I will try to get my hands on some more different encoders to see if I can reproduce this problem you are having. I may be able to speed up the processing routines in the software to improve performance.

Editor's comment: see also the letter regarding a similar problem on page 13.

More Signal Generator encoder problems

I have built the RF Signal Generator which works well, apart from some erratic rotary encoder operation. I think it might be due to contact bounce.

Is this a common problem, and is there a hardware- or software-based solution? One manufacturer, Bournes, suggests a hardware-based solution. Would I need to disable the internal pull-up resistors to allow this? Am I missing something obvious? (P. R., Linden, NSW)

• Andrew Woodfield responds: some low-cost encoders can cause this. The internal programmed pull-ups are necessary for correct operation, so if these are disabled, the encoder won't work unless you replace them with external pull-ups.

Online forums have debated the use of external capacitors for debouncing, but conclusions are divided. Some are firmly in favour, others equally vehemently opposed.

I suspect a wide variety of encoders can produce considerable variation, which can also make determining a 'best solution' difficult.

My suggestion is to try a different encoder. Failing that, or while you wait

for delivery on a different encoder, you could experiment with debouncing timing networks.

However, after a dozen or more different designs and testing several dozen encoders of various makes, albeit almost all cheaper types, I've not found them useful.

Sourcing parts for DAB+/FM/AM Radio

I have been gathering the components together to build the DAB+/FM/AM Radio tuner. However, there are still three components where I am having trouble on which part to order from the vast range of items available.

For example, with the 74HC14 hex Schmitt trigger inverter IC (IC7), there are many variants available from Mouser.

For the 10µF and 4.7µF X5R 0805 SMD capacitors, I think a 6.3V rating is suitable. But that still leaves a wide range of choices. Can you help me decide which ones to choose? (J. C., Kaleen, ACT)

● Any parts which match the requirements in the parts list should be fine. For reference, an SN74HC14DR from Digi-Key will work. When looking at the likes of Mouser or Digi-Key, we start with a search for the basic parameters, then dial in the other required specifications. For example, search for "10uF ceramic capacitor" and then set the filters to dielectric = X5R, package/case = 0805 (2012 metric), voltage rating = 6.3V etc.

We also set the filter so that only items that are in stock and available as single buys are listed; many parts are only in bulk, eg, reels of 3000 pieces. Setting packaging = "Cut Tape" should remove most of the bulk packaging options.

After that, simply choose the cheapest option. Many of the more expensive options will be for wide temperature use, military-grade, automotive-grade etc. You can click on the top of the Unit Price column to sort by price. The large number of options is due to the huge number of manufacturers for common parts.

Troubleshooting Digital Sound Effects module

I recently purchased two of your Super Digital Sound Effects Module kits (August-September 2018; siliconchip.com.au/Series/325). The first unit worked initially, but died shortly afterwards. I checked the supply voltages at all the chips, and they are correct. I also checked the pins for dry joints and shorts to adjacent pins.

Without a micro SD card, the blue LED flashes fast. With a card inserted, I get three flashes, pause, three flashes etc. I've tried five different cards, is there a particular format required? I re-loaded the software (0110718A.HEX) with a PICkit 3 via MPLAB X IPE, but it didn't help. (D. H., Norfolk, UK)

● The three flashes indicate a file system error. The file system library we've used supports standard FAT or exFAT file systems. We formatted the card we used to test our prototype using the Windows format utility.

An incorrectly formatted card would be enough to stop the module from working. Possibly, your card contains a FAT32 file system which is not supported by our software. FAT32 is the default for higher capacity cards. You could try a smaller capacity card to see if that helps.

The continuous flashing indicates a card is not present. Even without a card, you can check the audio operation by following the instructions under the "Testing" heading on page 82 of our September 2018 issue.

We have also used the SD Formatter tool from the SD Association; see: www.sdcard.org/downloads/formatter/ This can handle some cards that Windows can't.

The SD card communication and other board activities are not easy to diagnose just from waveforms. You could need an oscilloscope with SPI decoding capability, and a good knowledge of SD card operation to have any chance of figuring out the problem that way.

Changing Motor Speed Controller supply

I am building the Full-wave Triac-based Universal Motor Speed Controller (March 2018; siliconchip.com.au/Article/10998). I noticed that the power supply is made using two zener diodes (ZD1 and ZD2) and a half-wave rectifier (diodes D1 and D2), together with two 47Ω resistors and a 470nF X2 capacitor.

I would prefer to use a proper AC/DC converter, such as MEAN WELL RS-15-5 enclosed power supply. I was thinking to leave off your power supply components and inject power directly into the 5V rail using such a converter.

Would that be possible without any further modification? Would changing the power supply affect the microcontroller operation in any way? (A. L., Škofljica, Slovenia)

● The circuit works well using the power supply derived via the 470nF capacitor. We are not sure what benefits you expect from using a bulky 3A power supply as less than 30mA is required to run the circuit.

The 5V supply in this design floats at mains Active potential. The motor controller may still work using your suggested supply, but you would need to make sure that the output of the supply can float at Active potential without internal insulation breakdown. Additionally, switchmode noise from the converter could adversely affect microcontroller IC1's operation.

We therefore cannot recommend your suggested modification, nor can we guarantee that it will work as intended.

TV antenna tube thickness

I am considering making the 6-Element VHF Yagi for TV reception from the February 2018 issue (siliconchip.com.au/Article/10965). I have access to square and round aluminium tubing of the outside dimensions described in the article, however, in both cases, the walls are thicker than that described in the article. Does the wall thickness affect the performance in any way?

● Due to the skin effect (see link below), the current flowing in the antenna is mostly limited to the outer surface of the rods, with minimal penetration into the depth of the material. So using thicker material will not affect the antenna performance.

However, the extra thickness will add to the mass of the overall antenna, making it heavier but stronger (and probably more resistant to damage from birds).

See: https://en.wikipedia.org/wiki/Skin_effect

Can TP4056 module charge multiple cells?

I was reading your article on the TP4056 Li-ion charger module (Cat

SC4306) in your August 2017 issue (siliconchip.com.au/Article/10754), and I was wondering whether one module can be used to charge two Li-ion cells in parallel. How should I limit the cell voltage to 4.2V, or is that automatic?

If the battery has two cells in series (nominally 7.2V, fully charged at 8.4V), could two TP4056 modules be connected in series to charge it?

• We don't think that the little TP4056 charger module can handle two Li-ion cells in parallel at the same time, unless they are very low capacity cells. It would be safer to use two of them, each charging a single cell. The TP4056 does include circuitry to limit the cell voltage to 4.2V.

It would theoretically be possible to use two of these modules with their outputs in series to charge a two-cell battery, but you would need to run them from separate 5V plugpacks. Since the negative output of one will be connected to the positive output of the other, this would 'short out' the supply if they were both powered from the same 5V source.

Ultrasonic Anti-fouling low-battery cutout

I built your Marine Ultrasonic Anti-Fouling unit (May-June 2017; siliconchip.com.au/Series/312). When initially installed, it was working fine; I could hear the transducer clicking and see the neon light flashing more or less continuously.

But after I added a second transducer, both transducers click and the neons light up for about three seconds. Then nothing happens for about 30 seconds before they start operating for around three seconds again. The cycle then repeats. Is this normal?

The green LED flashes while the neons are flickering, then switches on solid for the 30 seconds while the neons are off. This happens only when both transducers are connected. When I remove the second transducer, the green LED is flickering continuously, and the neon is also on continuously.

• The clicks do not necessarily mean too much, as the noise is an audible by-product of the ultrasonic switching. The neon indicators are the best way of telling if the outputs are being driven.

Based on your description, it seems that there is a fault where the 12V power supply drops in voltage and the Ultrasonic Anti-fouling unit has to restart.

Is your 12V battery maintaining voltage? Check its voltage with a multimeter while the unit is running. Make sure that the low-battery detection is adjusted correctly, as it could be triggering at too high a voltage.

Silicon Chip engine management solutions

We have modified a 1986 Volkswagen Jetta, with the old 1.8L two-valve engine replaced with a more modern 2L unit to decrease emissions and improve torque. These engines have a Hall Effect distributor, with the ignition advance and retard being controlled by a dedicated ECU, separate from the fuel control ECU.

Do you know of any Jaycar kit to override the original spark and fuel maps to suit the demands of our modified engine?

We prefer to keep the original trouble-free distributor assembly with its Hall Effect sensor, but if required, can fit a wasted spark or COP system. I am aware of a kit offered by dkubus of Kudla, SA but it requires the purchase of a dkubus module and Microsquirt totalling well over $1000.

The Bosch fuel management system on these vehicles includes a separate cold-air sensor which overrules the ECU's standard mixture settings as required. Can this feature be commandeered to instruct the ECU to supply fuel mixtures better suited to our engine? (D. B., Vancouver, Canada)

• We published a Programmable Ignition System (March-June 2007; siliconchip.com.au/Series/56). This can be used to adjust the ignition timing from the Hall Effect trigger.

There was a Jaycar kit for this project, but it has unfortunately been discontinued. You can still build it using the PCBs and programmed microcontroller from our Online Shop. See: siliconchip.com.au/Shop/?article=2165

The other parts are commonly available from Jaycar, Altronics etc.

As far as the fuel mixture is concerned, we published an Automotive Sensor Modifier (December 2016; siliconchip.com.au/Article/10451) that can remap the voltage output from a sensor. This may suit your purpose of using the cold-air sensor output to modify the fuel mixture. The modifier is a one-dimensional mapped single input/single output type.

SD card socket has been discontinued

Do you have any suggestions for an SD card socket replacement for the CLASSiC DAC? It appears that the Altronics P5720 specified is no longer available. (K. R., Camperdown, NSW)

• We contacted Altronics and unfortunately, they were forced to discontinue this part as the supplier is no longer manufacturing it. We spent quite some time looking for compatible parts, but it appears that there are none.

We used this socket in six projects:

1) Digital Lighting Controller (October-December 2010; siliconchip.com.au/Series/14)
2) Maximite Computer (March-May 2011; siliconchip.com.au/Series/30)
3) LED Musicolour (October & November 2012; siliconchip.com.au/Series/19)
4) CLASSiC DAC (February-May 2013; siliconchip.com.au/Series/63)
5) GPS Tracker (November 2013; siliconchip.com.au/Article/5449)
6) Touch-screen Digital Audio Recorder (June & July 2014; siliconchip.com.au/Series/270)

All the PCBs for these projects will need to be re-designed to use a commonly available (and hopefully physically compatible) SD card socket.

Once we have done that, we will upload the new patterns to our website and order new stock. In the meantime, we will try to get our hands on a few of the discontinued sockets so that we can supply them to constructors until the new PCBs are ready.

Our more recent projects tend to use microSD cards, and those sockets are widely available, so those projects should hopefully be future-proof.

Unexpected voltage on preamp output grounds

I assembled your Ultra-LD Stereo Preamplifier & Input Selector (November & December 2011; siliconchip.com.au/Series/34) from an Altronics kit, Cat K5169. I measured -4.24V on the left RCA socket surrounds, and +14.32V on the right RCA socket surrounds. The audio ground appears to be floating. Is this normal, or have I done something wrong?

PRINTED CIRCUIT BOARDS

NOTE: The listings below are for the PCB ONLY. If you want a kit, check our store or contact the kit suppliers advertising in this issue. For unusual projects where kits are not available, some have specialised components available – see the list opposite.

NOTE: Not all PCBs are shown here due to space limits but the SILICON CHIP Online Shop has boards going back to 2001 and beyond. For a complete list of available PCBs etc, go to *siliconchip.com.au/shop/8*   Prices are PCBs only, NOT COMPLETE KITS!

PRINTED CIRCUIT BOARD TO SUIT PROJECT:	PUBLISHED:	PCB CODE:	Price:
VOLTAGE/RESISTANCE/CURRENT REFERENCE	AUG 2015	04108151	$2.50
LED PARTY STROBE MK2	AUG 2015	16101141	$7.50
ULTRA-LD MK4 200W AMPLIFIER MODULE	SEP 2015	01107151	$15.00
9-CHANNEL REMOTE CONTROL RECEIVER	SEP 2015	15108151	$15.00
MINI USB SWITCHMODE REGULATOR MK2	SEP 2015	18107152	$2.50
2-WAY PASSIVE LOUDSPEAKER CROSSOVER	OCT 2015	01205141	$20.00
ULTRA LD AMPLIFIER POWER SUPPLY	OCT 2015	01109111	$15.00
ARDUINO USB ELECTROCARDIOGRAPH	OCT 2015	07108151	$7.50
FINGERPRINT SCANNER – SET OF TWO PCBS	NOV 2015	03109151/2	$15.00
LOUDSPEAKER PROTECTOR	NOV 2015	01110151	$10.00
LED CLOCK	DEC 2015	19110151	$15.00
SPEECH TIMER	DEC 2015	19111151	$15.00
TURNTABLE STROBE	DEC 2015	04101161	$5.00
CALIBRATED TURNTABLE STROBOSCOPE ETCHED DISC	DEC 2015	04101162	$10.00
VALVE STEREO PREAMPLIFIER – PCB	JAN 2016	01101161	$15.00
VALVE STEREO PREAMPLIFIER – CASE PARTS	JAN 2016	01101162	$20.00
QUICKBRAKE BRAKE LIGHT SPEEDUP	JAN 2016	05102161	$15.00
SOLAR MPPT CHARGER & LIGHTING CONTROLLER	FEB/MAR 2016	16101161	$15.00
MICROMITE LCD BACKPACK, 2.4-INCH VERSION	FEB/MAR 2016	07102121	$7.50
MICROMITE LCD BACKPACK, 2.8-INCH VERSION	FEB/MAR 2016	07102122	$7.50
BATTERY CELL BALANCER	MAR 2016	11111151	$6.00
DELTA THROTTLE TIMER	MAR 2016	05102161	$15.00
MICROWAVE LEAKAGE DETECTOR	APR 2016	04103161	$5.00
FRIDGE/FREEZER ALARM	APR 2016	03104161	$5.00
ARDUINO MULTIFUNCTION MEASUREMENT	APR 2016	04116011/2	$15.00
PRECISION 50/60Hz TURNTABLE DRIVER	MAY 2016	04104161	$15.00
RASPBERRY PI TEMP SENSOR EXPANSION	MAY 2016	24104161	$5.00
100DB STEREO AUDIO LEVEL/VU METER	JUN 2016	01104161	$15.00
HOTEL SAFE ALARM	JUN 2016	03106161	$5.00
UNIVERSAL TEMPERATURE ALARM	JULY 2016	03105161	$5.00
BROWNOUT PROTECTOR MK2	JULY 2016	10107161	$10.00
8-DIGIT FREQUENCY METER	AUG 2016	04105161	$10.00
APPLIANCE ENERGY METER	AUG 2016	04116061	$15.00
MICROMITE PLUS EXPLORE 64	AUG 2016	07108161	$5.00
CYCLIC PUMP/MAINS TIMER	SEPT 2016	10108161/2	$10.00/pair
MICROMITE PLUS EXPLORE 100 (4 layer)	SEPT 2016	07109161	$20.00
AUTOMOTIVE FAULT DETECTOR	SEPT 2016	05109161	$10.00
MOSQUITO LURE	OCT 2016	25110161	$5.00
MICROPOWER LED FLASHER	OCT 2016	16109161	$5.00
MINI MICROPOWER LED FLASHER	OCT 2016	16109162	$2.50
50A BATTERY CHARGER CONTROLLER	NOV 2016	11111161	$10.00
PASSIVE LINE TO PHONO INPUT CONVERTER	NOV 2016	01111161	$5.00
MICROMITE PLUS LCD BACKPACK	NOV 2016	07110161	$7.50
AUTOMOTIVE SENSOR MODIFIER	DEC 2016	05111161	$10.00
TOUCHSCREEN VOLTAGE/CURRENT REFERENCE	DEC 2016	04110161	$12.50
VI REFERENCE CASE PIECES (MATTE BLACK / BLUE)	DEC 2016	SC4084/193	$10.00
SC200 AMPLIFIER MODULE	JAN 2017	01108161	$10.00
60V 40A DC MOTOR SPEED CON. CONTROL BOARD	JAN 2017	11112161	$10.00
60V 40A DC MOTOR SPEED CON. MOSFET BOARD	JAN 2017	11112162	$12.50
GPS SYNCHRONISED ANALOG CLOCK	FEB 2017	04202171	$10.00
ULTRA LOW VOLTAGE LED FLASHER	FEB 2017	16110161	$2.50
POOL LAP COUNTER	MAR 2017	19102171	$15.00
STATIONMASTER TRAIN CONTROLLER	MAR 2017	09103171/2	$15.00/set
EFUSE	APR 2017	04102171	$7.50
SPRING REVERB	APR 2017	01104171	$12.50
6GHz+ 1000:1 PRESCALER	MAY 2017	04112162	$7.50
MICROBRIDGE	MAY 2017	24104171	$2.50
MICROMITE LCD BACKPACK V2	MAY 2017	07104171	$7.50
10-OCTAVE STEREO GRAPHIC EQUALISER PCB	JUN 2017	01105171	$12.50
10-OCTAVE STEREO GRAPHIC EQUALISER FRONT PANEL	JUN 2017	01105172	$15.00
10-OCTAVE STEREO GRAPHIC EQUALISER CASE PIECES	JUN 2017	SC4281	$15.00
RAPIDBRAKE	JUL 2017	05105171	$10.00
DELUXE EFUSE	AUG 2017	18106171	$15.00
DELUXE EFUSE UB1 LID	AUG 2017	SC4316	$5.00
MAINS SUPPLY FOR BATTERY VALVES (INC. PANELS)	AUG 2017	18108171-4	$25.00
3-WAY ADJUSTABLE ACTIVE CROSSOVER	SEPT 2017	01108171	$20.00
3-WAY ADJUSTABLE ACTIVE CROSSOVER PANELS	SEPT 2017	01108172/3	$20.00/pair
3-WAY ADJUSTABLE ACTIVE CROSSOVER CASE PIECES	SEPT 2017	SC4403	$10.00
6GHz+ TOUCHSCREEN FREQUENCY COUNTER	OCT 2017	04110171	$10.00
6GHz+ FREQUENCY COUNTER CASE PIECES (SET)	OCT 2017	SC4444	$15.00
KELVIN THE CRICKET	OCT 2017	08109171	$10.00
SUPER-7 SUPERHET AM RADIO PCB	DEC 2017	06111171	$25.00
SUPER-7 SUPERHET AM RADIO CASE PIECES	DEC 2017	SC4464	$25.00
THEREMIN	JAN 2018	23112171	$12.50
PROPORTIONAL FAN SPEED CONTROLLER	JAN 2018	05111171	$2.50
WATER TANK LEVEL METER (INCLUDING HEADERS)	FEB 2018	21110171	$7.50
10-LED BARAGRAPH	FEB 2018	04101181	$7.50
10-LED BARAGRAPH SIGNAL PROCESSING	FEB 2018	04101182	$5.00
TRIAC-BASED MAINS MOTOR SPEED CONTROLLER	MAR 2018	10102181	$10.00
VINTAGE TV A/V MODULATOR	MAR 2018	02104181	$7.50
AM RADIO TRANSMITTER	MAR 2018	06101181	$7.50
HEATER CONTROLLER	APR 2018	10104181	$10.00

PRINTED CIRCUIT BOARD TO SUIT PROJECT:	PUBLISHED:	PCB CODE:	Price:
DELUXE FREQUENCY SWITCH	MAY 2018	05104181	$7.50
USB PORT PROTECTOR	MAY 2018	07105181	$2.50
2 x 12V BATTERY BALANCER	MAY 2018	14106181	$2.50
USB FLEXITIMER	JUNE 2018	19106181	$7.50
WIDE-RANGE LC METER	JUNE 2018	04106181	$5.00
WIDE-RANGE LC METER (INCLUDING HEADERS)	JUNE 2018	SC4618	$7.50
WIDE-RANGE LC METER CLEAR CASE PIECES	JUNE 2018	SC4609	$7.50
TEMPERATURE SWITCH MK2	JUNE 2018	05105181	$7.50
LiFePO4 UPS CONTROL SHIELD	JUNE 2018	11106181	$5.00
RASPBERRY PI TOUCHSCREEN ADAPTOR (TIDE CLOCK)	JULY 2018	24108181	$5.00
RECURRING EVENT REMINDER	JULY 2018	19107181	$5.00
BRAINWAVE MONITOR (EEG)	AUG 2018	25107181	$10.00
SUPER DIGITAL SOUND EFFECTS	AUG 2018	01107181	$2.50
DOOR ALARM	AUG 2018	03107181	$5.00
STEAM WHISTLE / DIESEL HORN	SEPT 2018	09106181	$5.00
DCC PROGRAMMER	OCT 2018	09107181	$5.00
DCC PROGRAMMER (INCLUDING HEADERS)	OCT 2018	09107181	$7.50
OPTO-ISOLATED RELAY (WITH EXTENSION BOARDS)	OCT 2018	10107181/2	$7.50
GPS-SYNCHED FREQUENCY REFERENCE	NOV 2018	04107181	$7.50
LED CHRISTMAS TREE	NOV 2018	16107181	$5.00
DIGITAL INTERFACE MODULE	NOV 2018	16107182	$2.50
TINNITUS/INSOMNIA KILLER (JAYCAR VERSION)	NOV 2018	01110181	$5.00
TINNITUS/INSOMNIA KILLER (ALTRONICS VERSION)	NOV 2018	01110182	$5.00
HIGH-SENSITIVITY MAGNETOMETER	DEC 2018	04101011	$12.50
USELESS BOX	DEC 2018	08111181	$7.50
FOUR-CHANNEL DC FAN & PUMP CONTROLLER	DEC 2018	05108181	$5.00
ATtiny816 DEVELOPMENT/BREAKOUT BOARD	JAN 2019	24110181	$5.00
ISOLATED SERIAL LINK	JAN 2019	24107181	$5.00
DAB+/FM/AM RADIO	JAN 2019	06112181	$15.00
DAB+/FM/AM RADIO CASE PIECES (CLEAR)	JAN 2019	SC4849	$.00
TOUCH & IR REMOTE CONTROL DIMMER MAIN PCB	FEB 2019	10111191	$10.00
REMOTE CONTROL DIMMER MOUNTING PLATE	FEB 2019	10111192	$10.00
REMOTE CONTROL DIMMER EXTENSION PCB	FEB 2019	10111193	$10.00
MOTION SENSING SWITCH (SMD) PCB	FEB 2019	05102191	$2.50
USB MOUSE AND KEYBOARD ADAPTOR PCB	FEB 2019	24311181	$5.00
REMOTE-CONTROLLED PREAMP WITH TONE CONTROL	MAR 2019	01111119	$25.00
PREAMP INPUT SELECTOR BOARD	MAR 2019	01111112	$15.00
PREAMP PUSHBUTTON BOARD	MAR 2019	01111113	$5.00
DIODE CURVE PLOTTER	MAR 2019	04112181	$7.50
DIODE CURVE PLOTTER UB3 LID (MATTE BLACK)	MAR 2019	SC4927	$5.00
FLIP-DOT COIL	APR 2019	19111181	$5.00
FLIP-DOT PIXEL (INCLUDES 16 PIXELS)	APR 2019	19111182	$5.00
FLIP-DOT FRAME (INCLUDES 8 FRAMES)	APR 2019	19111183	$5.00
FLIP-DOT DRIVER	APR 2019	19111184	$5.00
FLIP-DOT (SET OF ALL FOUR PCBS)	APR 2019	SC4950	$17.50
iCESTICK VGA ADAPTOR	APR 2019	02103191	$2.50
UHF DATA REPEATER	MAY 2019	15004191	$10.00
AMPLIFIER BRIDGE ADAPTOR	MAY 2019	01105191	$5.00
3.5-INCH SERIAL LCD ADAPTOR FOR ARDUINO	MAY 2019	24111181	$5.00
DSP CROSSOVER/EQUALISER ADC BOARD	MAY 2019	01106191	$7.50
DSP CROSSOVER/EQUALISER DAC BOARD	MAY 2019	01106192	$7.50
DSP CROSSOVER/EQUALISER CPU BOARD	MAY 2019	01106193	$5.00
DSP CROSSOVER/EQUALISER PSU BOARD	MAY 2019	01106194	$7.50
DSP CROSSOVER/EQUALISER CONTROL BOARD	MAY 2019	01106195	$5.00
DSP CROSSOVER/EQUALISER LCD ADAPTOR	MAY 2019	01106196	$2.50
DSP CROSSOVER (SET OF ALL BOARDS – TWO DAC)	MAY 2019	SC5023	$40.00
STEERING WHEEL CONTROL IR ADAPTOR	JUNE 2019	05105191	$5.00
GPS SPEEDO/CLOCK/VOLUME CONTROL	JUNE 2019	01104191	$7.50
GPS SPEEDO ACRYLIC CASE PIECES (MATTE BLACK)	JUNE 2019	SC4987	$10.00
RF SIGNAL GENERATOR	JUNE 2019	04106191	$15.00
RASPBERRY PI SPEECH SYNTHESIS/AUDIO	JULY 2019	01106191	$5.00
BATTERY ISOLATOR CONTROL BOARD	JULY 2019	05106191	$7.50
BATTERY ISOLATOR MOSFET BOARD (2oz)	JULY 2019	05106192	$10.00
MICROMITE LCD BACKPACK V3	AUG 2019	07106191	$7.50
CAR RADIO DIMMER ADAPTOR/VOLTAGE INTERCEPTOR	AUG 2019	05107191	$5.00
PSEUDO-RANDOM NUMBER GENERATOR (LFSR)	AUG 2019	16106191	$5.00
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MICROMITE EXPLORE-28 (4-LAYERS)	SEPT 2019	07108191	$5.00
SIX INPUT AUDIO SELECTOR MAIN BOARD	SEPT 2019	01110191	$7.50
SIX INPUT AUDIO SELECTOR PUSHBUTTON BOARD	SEPT 2019	01110192	$5.00
ULTRABRITE LED DRIVER	SEPT 2019	16109191	$2.50
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PRECISION AUDIO SIGNAL AMPLIFIER	OCT 2019	04107191	$5.00

NEW PCBs

SUPER-9 STEREO FM RADIO (SET OF ALL PCBS REQ.)	**NOV 2019**	**06109181-5**	**$25.00**
SUPER-9 CASE PIECES & DIAL (BLACK / CLEAR)	**NOV 2019**	**SC5166**	**$25.00**
TINY LED XMAS TREE (CHOICE OF GREEN/RED/WHITE)	**NOV 2019**	**16111191**	**$2.50**
HIGH POWER LINEAR BENCH SUPPLY	**NOV 2019**	**18111181**	**$10.00**
LINEAR BENCH SUPPLY HEATSINK SPACER (BLACK)	**NOV 2019**	**SC5168**	**$5.00**
FIVE-WAY LCD PANEL METER / USB DISPLAY	**NOV 2019**	**18111182**	**$2.50**
LCD PANEL METER BEZEL (BLACK)	**NOV 2019**	**SC5167**	**$2.50**

WE ALSO SELL AN A2 REACTANCE WALLCHART, RTV&H DVD, VINTAGE RADIO DVD PLUS VARIOUS BOOKS IN THE "Books, DVDs, etc" PAGE AT SILICONCHIP.COM.AU/SHOP/3

I grounded the RCA sockets with a piece of wire across to the 0V terminal and plugged it into an SC200 amplifier module (January-March 2017; siliconchip.com.au/Series/308). All appeared to be normal, but 10 minutes later, the amplifier module appeared to have failed.

This amplifier had been used for about 10 hours without problems, being driven direct from the DAC. I read about SC200 oscillation on a forum that mentioned specific input configurations caused it. I wonder if the preamp has caused something strange to happen to the SC200. (D. B., South Burnie, Tas)

• The RCA grounds are floating and rely upon the RCA plugs forming a ground connection to the main amplifier. This avoids hum loops. The preamp supply ground connects to the power amplifier supply ground that is then connected to the signal ground (and the RCA grounds) at a single central point. This is called a star earth, and it avoids hum loops.

The supply voltage of around +15V should not appear on the RCA socket grounds. You should find and fix this before connecting to the SC200 amplifier. We think that may be the reason why the power amplifier was damaged. Check the wire linking on the supply from CON6.

Vented steel case for 12V Stereo Amplifier

I'm currently studying year 12 digital technologies. For my project, I am building your Compact High-Performance 12V Stereo Amplifier (May 2010; siliconchip.com.au/Article/152) from a Jaycar kit (Cat K5136). The photos show the amplifier in a vented metal case. It would be great if I could get my hands on one of these, but I can't find that case anywhere online. (L. H., via email)

• The case is specified in the parts list for that project as the Jaycar HB5444 vented aluminium case. Jaycar has discontinued that product and it is no longer available, but they still have smaller (HB5442) and larger (HB5446) versions of the same case.

The amplifier board should fit in the smaller case as long as you use a small enough heatsink. It will definitely fit in the larger case. You can also try Metcase (https://www.metcase.com.au/en) if you want a custom-fit case.

Finding a replacement axial inductor

I wonder if you can help me with a small problem. I have an axial inductor, which looks like a resistor. Its value is 150μH, but I don't know its power rating.

I am guessing based on its size that it is either 0.25W or 0.5W. The body is approximately 5mm long and 2.5mm wide. It's marked CH15014 on the PCB. It's in a 1.2V-to-3V DC/DC converter stage in a solar garden light.

I can't find any information online for comparing physical inductor size to wattage, so I hope you can help me with this. I was surprised that there doesn't seem to be any information about this available. Do you know what the wattage would be? (B. P., Dundathu, Qld)

• Inductors are generally not rated in terms of watts. They do have a power limit of course, but they often run into core saturation (where the effective inductance drops precipitously) before they reach an unsafe dissipation level.

You will typically find inductor ratings indicated in amps. The maximum limit may be due to core saturation or maximum dissipation (as determined by the DC resistance), whichever is lower.

Consider the specifications for the Altronics L7036 and Jaycar LF1536 150μH axial inductors, which appear to be virtually identical. They're both rated at 175mA with a DC resistance of 4.2Ω. That equates to about 0.125W maximum dissipation. They appear to be physically larger than the one you're talking about, at 11mm long and 4mm in diameter.

Hence, your inductor is probably rated at no more than about 0.1W. If you can fit either of these parts in the same space, they should be suitable substitutes.

Where to get common-mode chokes

In Circuit Notebook, October 2010, there is an entry called the "Auto-sensing master/slave power control" (siliconchip.com.au/Article/321). Transformers T1 and T2 in this circuit are described as line voltage filters from old computer power supplies, one needing a cut to prevent saturation.

Are there suitable parts that I can purchase from local component suppliers? One functions as a current transformer, the other as a line filter. Thank you in advance for any help you can offer. (F. C., Maroubra, NSW)

• There isn't much detail in the article about those parts, but they are probably basic common-mode chokes as used for mains line filtering. These are widely available. RS Components have two parts which are likely to be suitable (and probably many more), catalog codes 123-4268 and 816-4767.

Without more details such as the expected inductance and current rating, it's hard to say for sure whether these parts will work in the circuit you mention. But we would try one of those, or something similar from another supplier; Digi-Key and Mouser are bound to have plenty of such parts in stock too.

Is a DAC upgrade worthwhile?

I love the audio projects you publish and I have a question about them. Is the CLASSiC DAC (February-May 2013; siliconchip.com.au/Series/63) all that much better than your original stereo DAC (September-November 2009; siliconchip.com.au/Series/4), sold as a kit by Jaycar and Altronics?

My ageing ears can't hear the difference between my 2009 DAC driving an Ultra-LD Mk.3 amplifier (March-May 2012; siliconchip.com.au/Series/27), my Yamaha RX-V2400 and my Guangzhou SMSL DP3. Please keep the audio stuff coming. (R. R., Flinders, Vic)

• While the CLASSiC DAC does measure a bit better than the 2009 design, and we're convinced it sounds a bit better, it's hard to hear the difference most of the time.

The difference is only noticeable in certain passages of particular tracks. And you need a very good amplifier and speakers to be able to notice that difference.

Since you have already built the 2009 DAC, it probably isn't worth building the CLASSiC DAC just for the slightly improved sound quality. But if you were building a DAC from scratch, we recommend the CLASSiC DAC.

Note that you also have the option to upgrade the 2009 DAC to use the same chip as the CLASSiC DAC – see the Crystal DAC board (February 2012; siliconchip.com.au/Article/768).

Building a hearing loop

I recently got hearing aids due to a lifetime of industrial noise damage. Modern hearing aids combine audio from the microphone and telecoil, so there is no longer a requirement to choose between the transmitted audio and conversation in the room. Thus the telecoil seems ideal to allow me to rejoin my family for TV nights.

I searched your archives and was delighted to see that you had published a set of articles across two issues (September/October 2010) on "Designing and installing a hearing loop for the deaf".

Unfortunately, there is not enough information in the article for me to build my own hearing loop from scratch.

I intend to construct a hearing loop amplifier to take a TOSLINK input, convert it to analog, and drive a loop using either a voltage or current amplifier. Can you advise me how to do this? (D. J., Surf Beach, NSW)

• We published a project article on building a Hearing Loop Signal Conditioner in the January 2011 issue (siliconchip.com.au/Article/876). This allows a standard audio amplifier to drive a hearing loop. Information on building the loop itself is in the articles you already mention.

You can purchase a TOSLINK-to-analog converter from Altronics (Cat A3195), Jaycar (Cat AC1723 or AC1715) or other suppliers. The stereo output can be mixed to mono using a pair of 4.7kΩ resistors, so that the mono signal can be fed to the Signal Conditioner. SC

Coming up in SILICON CHIP

Altronics Megabox V2

This new version of Altronics' Arduino Megabox uses an Arduino Uno or Mega and now has room for two shields and provides an LCD screen, five relays, eight opto-isolated inputs and much more. It will turn your *rat's-nest* Arduino prototype into a slick, professional-looking device.

The House of Electrical Horrors

Beware! There are lots of really unsafe electrical appliances available, especially from overseas vendors on sites like eBay and AliExpress. Dr David Maddison describes many of the worst offenders, with plenty of links to YouTube videos showing just how spectacularly dangerous they can be.

Tuneable HF Preamplifier

Many low-cost SDR modules have poor HF (3-30MHz) performance. Their wide-open front ends also make them susceptible to cross-modulation from strong signal sources. This simple tuneable preamp greatly improves SDR HF performance. It has adjustable gain control and can run off a 5V supply or phantom power.

Universal 6-24V Battery Charge Controller

This Battery Charge Controller turns a 'dumb' battery charger into a smart charger, suitable for use with various 6V, 12V or 24V batteries, including lead-acid, gel-cell, Li-ion and $LiFePO_4$ (lithium-ion phosphate). It has three preset charging profiles and three adjustable profiles with one to three-stage charging.

Note: these features are planned or are in preparation and should appear within the next few issues of SILICON CHIP.

The December 2019 issue is due on sale in newsagents by Thursday, November 28th. Expect postal delivery of subscription copies in Australia between November 25th and December 12th.

Notes & Errata

45V 8A Bench Supply, October 2019: in the circuit diagram (Fig.3) on pages 26 & 27, the 1nF capacitor between pins 1 & 2 of IC1a should be 100nF; D6 is an SB380 type; IC1 should have a 100nF bypass capacitor from its negative supply (pin 4) to ground; the 68Ω resistor below Q3 is a 1W type; the four 0.1Ω resistors are 1W, not 5W; the 100μF capacitor at the input of REG1 has a 63V rating; and if electrolytics are used for the two 1μF capacitors, their negative leads go to ground.
Vintage Radio (Kriesler 31-2), September 2019: the vibrator circuit (Fig.2) shown on page 115 was incorrectly redrawn. The vibrator reed should be shown not touching either of the two contacts.

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